A Novel Enhanced Mutual Coupling Reduction in Patch Antenna

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Abstract— A novel method by using Defected Ground Structures (DGSs) and Embedded Split Ring Resonators (ESRRs) to reduce mutual coupling between microstrip patch antennas is proposed. Using two band gap structures have improved the mutual coupling reduction in a low-profile volume. The proposed antenna has been fabricated and measurements show more than 40 dB and 50 dB isolation at 5% and 1% frequency bandwidth, respectively. Thus, the isolation has been improved more than 15 dB compare too array without band gap structures.

Index Terms— Microstrip patch antenna, defected ground structure, mutual coupling reduction and embedded split ring resonator.

1 INTRODUCTION

Microstrip antenna arrays are well known for being low cost, low profile, easy to design and fabricate. Their easy integration with RF circuit has made them as a good candidate for wireless communication. Thus, in the recent years a lot of research have been done to reach a compact and miniaturized microstrip antenna [1]. The microstrip patch antenna just can provide a medium range for the radiation gain, so they are used in antenna array to achieve a high gain antenna. However, one of the main drawback in the microstrip antenna array is the mutual coupling between antenna elements. The band gap structure such as DGS, Complimentary SRRs (CSRRs) and SRRs are used to achieve desired frequency response or miniaturized structure in the microwave circuits [2-6]. To decrease the mutual coupling, these band gap structures can be used to block the surface wave [7-9]. The DGS structures disturb the current distribution of antenna's ground plane. Thus, by controlling the shape of DGS, the propagation of electromagnetic waves in the substrate layer is controlled and the mutual coupling can be reduced [10].

In a microstrip antenna array, each radiating element affects the gain of other radiating elements in a way that the final performance of array degrades [11]. This effect increases especially in the application with miniaturized microstrip antennas if they are using in antenna arrays when the distance between the radiating elements decreases significantly [12]. In this paper, we used both CSRR and embedded SRRs (ESRRs) techniques to maximize the isolation between two adjacent antennas. The ESRRs has been proposed in [13] for the first time. In [14,15]is shown that they can provide an evanescence mode to avoid wave propagation in substrate. By using the ESRR and CSRRs elements between the antenna elements, a 45 dB-isolation has been achieved, which is a significant improvement over the 30 dB isolation reported in [7]. The both structure have been optimized in order to reduce the near-field coupling between the antennas elements while not degrade the radiation pattern, gain and efficiency of the antenna array. The provided unit cell model for band gap structures also have accelerate the design procedure to have more accurate results. The frequency band of 4200-4400 MHz is used which is internationally shared reserved for radio altimeters installed on aircrafts. Thus, this mutual coupling reduction can be used in full duplex communication as a further application, where a high isolation between Tx and Rx is needed [16].

2 SIMULATION, EXPERIMENTAL RESULTS AND DISCUSSION

The proposed two-element microstrip antenna array is illustrated in Figure. 1. It consists of a pair of adjacent microstrip patch antennas operate in altimeter frequency bandwidth (4200-4400 MHz). The proposed structure is printed on Rogers RO4003 substrate with ε_r=3.2, tan δ=0.0027. In order to cover the whole frequency bandwidth, the substrate thickness is chosen 120 mil. Increasing the thickness of substrate will consequently increase the surface wave and mutual coupling between two elements. In order to reduce the mutual coupling between the antenna elements, DGS and CSRRs structures along with parasitic elements have been employed in the antenna structure as shown in Figure. 1. SRRs can be modeled as a parallel LC resonant tank excited by a time-varying magnetic field [4]. The capacitance is a series combination of the capacitance between the rings in the upper and lower halves of the SRR. CSRRs are the dual counterparts of the SRRs. Their equivalent model can also be driven by electric fields [17]. In order to obtain a rejection-band in desired frequency bandwidth, the LC resonant tanks value should be adjusted as following: a) $C = r0\pi C_0/2$, where C_0 is the per-unit length capacitance in the gap between the rings, and r0 is the average CSRRs radius and b) L is the total inductance of CSRRs. The proposed unit cell resonator (CSRR with slot) shows a wide stop band behavior which can be considered as two cascaded filters. The size of outer ring is

4mm×4mm ($0.06\lambda_0$ ×$0.06\lambda_0$) with element spacing of 6mm ($0.06\lambda_0$). The unit cell is simulated with CST software's Eigen mode solver. As shown in Figure. 2, the resonance frequencies are about 4.35 GHz and 4.75 GHz. These two resonant frequencies are the center frequencies of the rejection bands. The higher and lower frequencies are the results of the outer ring the inner ring respectively. The unit cell is a slot with the length of Ls and width of Ws as indicated in Figure. 1. In the next step in order to increase the isolation between the antenna elements and decrease the surface wave, two rectangularslots of Length L_{slot}, and W_{slot} are inserted on the ground plane (see Figure. 1). The inserted elements on the ground, disturb the ground current distribution and results in achieving a wide reject band. These slots exhibit a rejection band at around 4.2 GHz as indicated in Figure.3. Final step is adding parasitic elements between microstrip antenna elements. These parasitic rectangular slots of Length L_p and width W_p are shortened to the ground plane by conducting pins. These parasitic elements reduce the near field coupling between the antennas. The electromagnetic energy couples to these parasitic elements and shorts to the ground plane by means of the conducting pins. It should be noted that these parasitic elements may degrade the radiation pattern of the array. Therefore, the shape of these parasitic elements should be optimized in order to not disturb the radiation pattern of the antenna. Thelength of the parasitic elements should be chosen between $\lambda/2$ to λ [18]. When the length of the parasitic elements decrease, the adverse effect on the antenna radiation pattern decreases too. At first, we set the resonance frequency of one parasitic element at 4.3 GHz. It is done by changing the position of the grounding pins, length and location of the slots, parasitic elements length and number (five elements). Using more number of parasitic elements, degrades the radiation pattern of antenna. We used linearly decreasing taper toward the antennas to decrease the disturbing effects on the radiation pattern. The proposed structure has been simulated with HFSS software. Figure 3 shows the mutual couplings of the proposed structure. In this Figure the mutual coupling of two microstrip antennas without any DGS and parasitic element, with the DGS structure and with the parasitic elements added are compared. All parameters have been optimized with HFSS using Particle Swarm Optimization (PSO) algorithm with the goal of improving the return loss and decreasing the mutual coupling. The optimized design parameters are listed in Table.1.

TABLE 1. Optimized parameter of the structure using PSO Algorithm with HFSS in mm.

L	**L_S**	**L_{P1}**	**L_{P2}**	**L_{P3}**	**L_{SLOT}**
4	2	60	40	20	20
G	W_S	W_{P1}	W_{P2}	W_{P3}	W_{SLOT}
1.5	0.15	2	1	1	2.5

Inserting the DGS structure in the ground plane has a filtering effect around 4.2 GHz (see Figure. 3). Moreover, the parasitic elements improve the pole around 4.25 GHz and also creates a new pole around 4.32GHz. As a result, in the whole frequency band of altimeter, the mutual coupling between elements is typically less than -45 dB. It means that 15 dB isolation improvement is achieved. High isolation between the transmitter and the receiver antennas is extremely desirable in applications where both transmitter and receiver operate simultaneously. Increasing the isolation between the transmitter and the receiver also prevents the receiver from saturation. In this work, -30 dB input power can saturate the receiver. Thus, if the power of transmitter is 0 dB, -30dB mutual coupling is not enough. In Figure. 4 the impedance matching performance of the antenna in three cases are also depicted. It is obvious that there is a significant impedance matching improvement in the whole frequency band when the DGS and parasitic elements are added to the structure. In Figure. 5 the radiation pattern of this structure is compared with the conventional microstrip patch antennas.

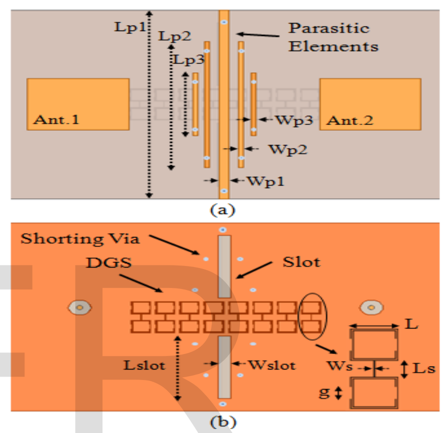


Figure 1. The proposed structure a) Top view and b) bottom view.

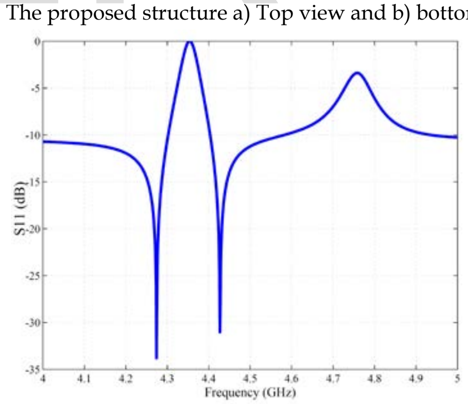


Figure 2. Eigen mode simulation of the unit cell with CST software.

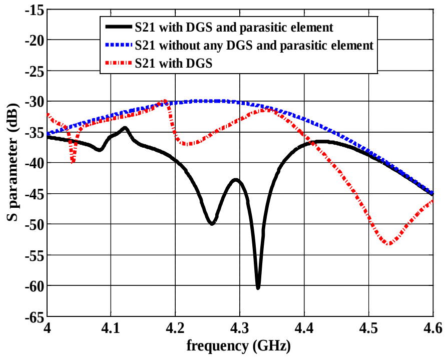


Figure 3. Comparison between the mutual coupling in the case of a) structure without DGS and parasitic elements b) Structure with DGS and c) structure with DGS and parasitic elements.

It has been shown that adding DGS and parasitic elements did not disturb the radiation pattern of the structure. Fabricated prototype is shown in Figure. 6. Thereturn loss and mutual coupling between the elements have been measured by network analyzer. The mutual coupling (S_{21}) is illustrated in Figure. 7.

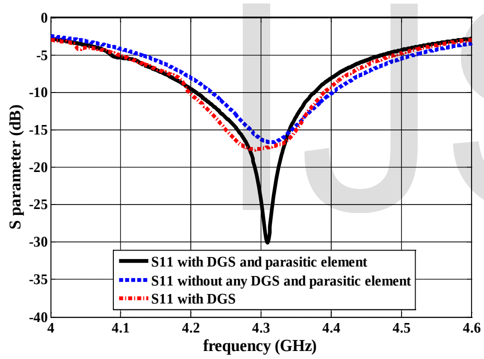


Figure 4. Comparison between the impedance matching in the case of a) structure without DGS and parasitic elements b) Structure with DGS and c) structure with DGS and parasitic elements.

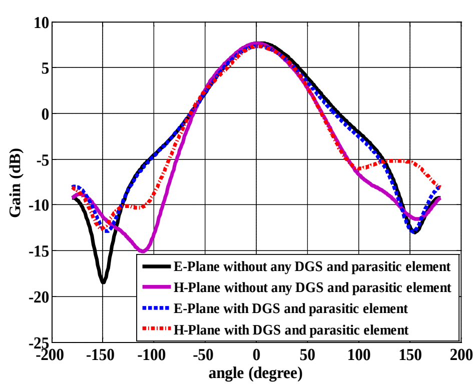
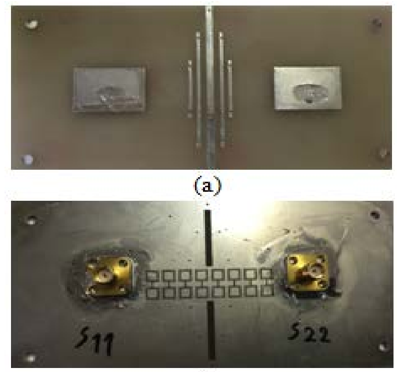


Figure 5. Comparison between the radiation pattern the case of a) structure without DGS and parasitic elements b) structure with DGS and parasitic elements.



(a)

(b)

Figure 6. Fabricated prototype a) Top view and b) bottom view.

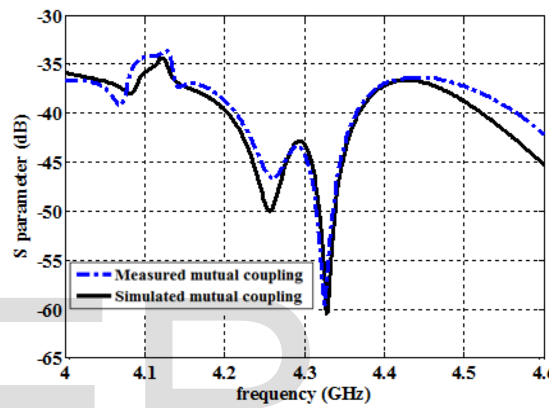


Figure 7. Comparison between the simulated and measured mutual coupling between two adjacent microstrip antennas.

4 Conclusion

An effective method to reduce the mutual coupling between microstrip patch antennas is proposed. One feature of this design is that the mutual coupling between two microstrip antennas is less than 40 dB in 85% of frequency bandwidth. Another feature is that the proposed structure includes a single ground plane results in small size and low cost fabrication. In addition, the parasitic elements do not disturb the radiation pattern and gain of the array.

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