A New Quad-band Diversity Antenna With High isolation

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***Abstract*—In this paper; a new high isolation planar antenna array for multiband applications is presented. The proposed antenna consists of annular-ring slots printed on FR_4 substrate and operates in quad-frequency bands for different applications such as DCS mobile communication/higher GSM/LTE 2500/WiMAX/HiperLAN bands. The isolation is achieved through a combination of hybrid isolation enhancement mechanisms. Firstly; the antennas are placed in an orthogonal arrangement to perform the required Polarization Diversity (PD) to increase the isolation issue. Then; a very thin planar Defected Wall Structure (DWS) is being inserted between antennas to suppress the direct space wave coupling. Moreover; additional non-radiating shorting strips are connecting the ground plane of each antenna to further increases port-to-port isolation. A good Isolation of more than 17 dB improvement over the reference antenna can be obtained in each band, for an antenna spacing less than 0.25 λ_0 of the lowest frequency. The proposed antenna is being investigated and verified both numerically and experimentally. The measurement and simulation results are in good agreement; a slight deviation can be attributed to the fabrication tolerances. Finally; the proposed antenna has been compared with previous works regarding antenna size, isolation level and geometric complexity. However; the proposed antenna has some outstanding characteristics such as a geometric simplicity, compact size, broad multibands bandwidth and low correlation which give the antenna an excellent diversity performance and a good candidate for multiband applications**.

Index Terms—Mutual coupling reduction; Slot Array; Multi-bands Antennas; Multiple-Input-Multiple-Output (MIMO).

I. INTRODUCTION

The reduction of mutual coupling between closely spaced antennas is necessary to the performance of Multiple Input Multiple Output (MIMO) systems since mutual coupling affects on antenna performance such as current distribution, phase, input impedance and radiation patterns in each antenna element which in turn significantly reduces the capacity of MIMO systems [1],[2].Antenna elements must be spaced by $\lambda_0/2$ to achieve low correlation and hence higher isolation between the elements, where λ_0 is the free space wavelength [2],[3]. However, degradation occurs when antenna elements are nearby, due to near-field coupling effects, surface waves and reactive mutual coupling between the elements [3], [4]. In recent years, the interest for multiband multi-antenna systems has been growing for multi-standard wireless terminals. In such multiband devices, achieving high isolation between the radiating elements is a challenging task, and also it's hard to control the isolation over the desired bands. So it gives a real challenge to antenna designers to produce an efficient MIMO system [1].

Efforts have been directed to eliminate or decrease the effects of mutual coupling between different microstrip antennas working in MIMO/diversity applications. Several techniques have been recently reported to reduce mutual coupling between radiating elements in multi-band MIMO applications. Some of these techniques are based on a Defected Ground Structure (DGS) [7], insertion of Electromagnetic Band Gap (EBG) structures [8], use of meta-material structures [9]. Resonators [10], Spatial and angular variation [12-13], Neutralization Line (NL) [14].etc.

In this paper, a combination of hybrid isolation enhancement mechanisms is effectively utilised to reduce the mutual coupling between two closely separated slot antenna array. Printed slot-array was chosen due to the demand for small size, ease of fabrication and low cost. The design of the proposed antenna is introduced in Section II, where antenna configuration is illustrated. The performance results of the proposed antenna system are illustrated and compared experimentally in Section III. While Section IV compares the proposed work with other approaches listed in the literature. Finally; the conclusions are given in Section V.

II. ANTENNA DESIGN AND CONFIGURATION

A. Antenna Element

Annular ring slot antennas have been of great interest to numerous researchers and engineers in recent decades [1]. Moreover, ring-slot antennas are easy to design; they have a relatively wide bandwidth and can be flexibly tuned by slight changes in their dimensions. In this work, we propose a simple design of a quad-frequency annular-ring slot antenna fed by microstrip line. Furthermore, the quad frequency characteristics of the annular-ring slot antenna are also investigated.

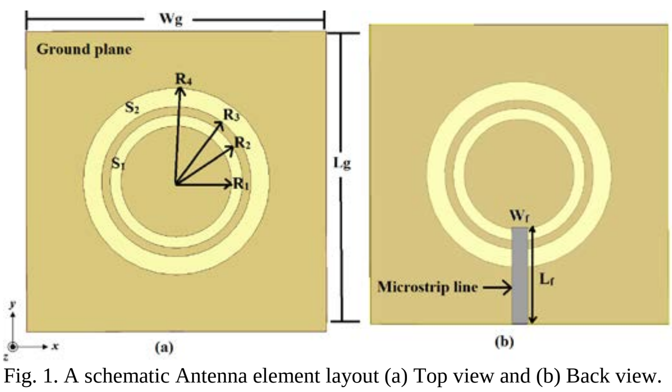


Fig. 1. A schematic Antenna element layout (a) Top view and (b) Back view.

Several optimisations of the proposed antenna by using Ansoft HFSS software version 17.0 have been performed, and the results present that the number of multiband, the centre of a frequency of each band and bandwidth can be controlled by the dimensions optimisation of these ring-slots. It should also be noted that the dimensions of the ground plane can affect bandwidths of the four modes [1].

Fig. 1(a) and (b) shows the schematic diagram of a single antenna element, two annular-ring slots (denoted by S_1 and S_2) with different radii (Fig.1(a)) were introduced for quad-bands operation with a copper ground plane printed on the same side of FR_4 substrate. On the other side of the square substrate, a 50 -Ω-microstrip line has adhered below the ground plane (the shaded area in Fig. 1(b)). The antenna dimensions obtained after optimization are as the following: substrate height (h) = 1.6 mm, ground plane length (L_g)= 65 mm, ground plane width (W_g)= 65 mm, feedline length (L_f)= 21 mm, feed line width (W_f)= 3.4 mm and radius R_1 = 12 mm, R_2 = 14 mm, R_3 = 16 mm and R_4 = 20 mm, space (S) = 40 mm and measured from element centre to centre (approximately equal 0.25 λ_0 of the lowest frequency band), finally; antenna element is made up of copper sheet with thickness of 0.2 mm.

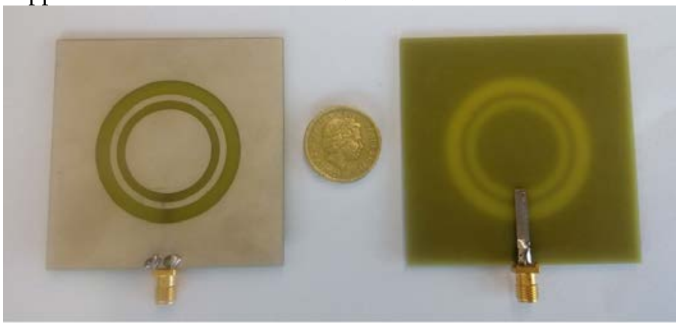


Fig. 2. A prototype of the fabricated single antenna element (Top and back view).

The proposed antennas were fabricated via the PCB etching process of an inexpensive FR_4 substrate having a thickness of 1.6 mm, dielectric permittivity constant of 4.4 (with a loss tangent of 0.017). The microstrip lines were fed through 50 Ω SMA. Photograph of the fabricated multiband antenna element is illustrated in Fig. 2.

B. *Design Procedures of Proposed Antenna*

As we mentioned earlier, the correlation between any two Antennas within a MIMO system should be kept as low as possible to improve the performance and capacity of MIMO systems. In this work; two identical antennas were designed and separated (back to back) by 40 mm (λ_0/4 at the lowest frequency, where λ_0 is the free space wavelength). Fig. 3 shows the proposed multiband antenna array.

Hybrid isolation enhancement mechanisms are combined and effectively utilised to reduce the mutual coupling between the proposed antennas. Firstly; Polarisation Diversity (PD) is achieved by arranging antenna microstrip line feeds orthogonally locating to each other to improve multiband isolation. Then; a very thin wall defected with metallic lattice pattern composes 3×3 circular slots (as shown in Fig. 3.) to form a planner defected wall structure (DWS) in between. However; the proposed defected wall has been optimised and intended for mutual coupling suppression, it can block the space wave propagation from the antenna elements and absorb part of fields at certain bands. Finally; isolation enhanced by introducing additional non-radiating shorting strips linking the ground plane of each antenna. This solution has been shown to act like neutralisation lines withdrawing an amount of the signal on one antenna and bringing it back to the other so that the mutual coupling is reduced.

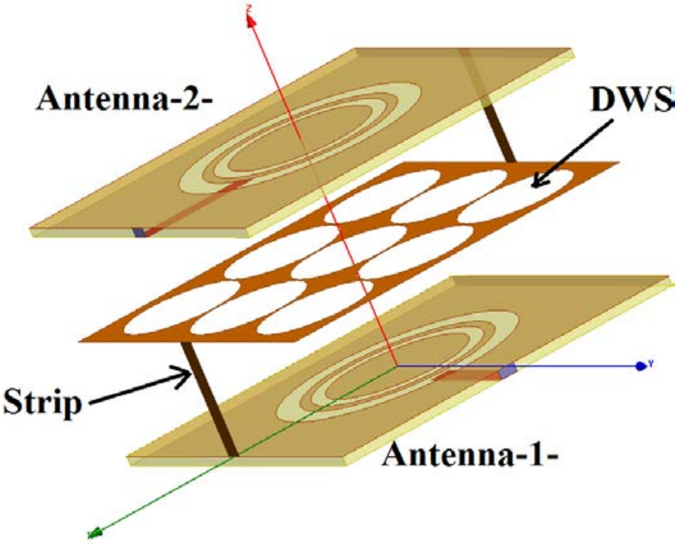


Fig. 3. 3D Perspective view showing the configuration of the proposed antenna array using hybrid methods: Thin DWS inserted in middle and two strips embedded from sides to reduce the near-field coupling. The polarisation diversity of the microstrip line feeds also shown.

The scattering parameters result along with the far-field radiation patterns will be discussed in the next section.

III. PERFORMANCE AND RESULTS

A. *Simulated and Measured Scattering Parameters*

To validate the simulation results, the proposed antenna array had been fabricated, tested, measured and then compared with simulated results. The performance of the proposed multiband antenna array has been verified through a measurement performed using Agilent Technologies N5230A PNA–L RF network vector analyser inside Brunel University London (as shown in Fig. 4.).

Fig. 4. Experimental setup for the reference (Right) and the proposed (Left) antenna array to measure the scattering parameters.

The measured and simulated scattering parameter plots (return and transmission losses) for both reference and the proposed antenna are presented in Fig. 5(a) and (b); respectively.

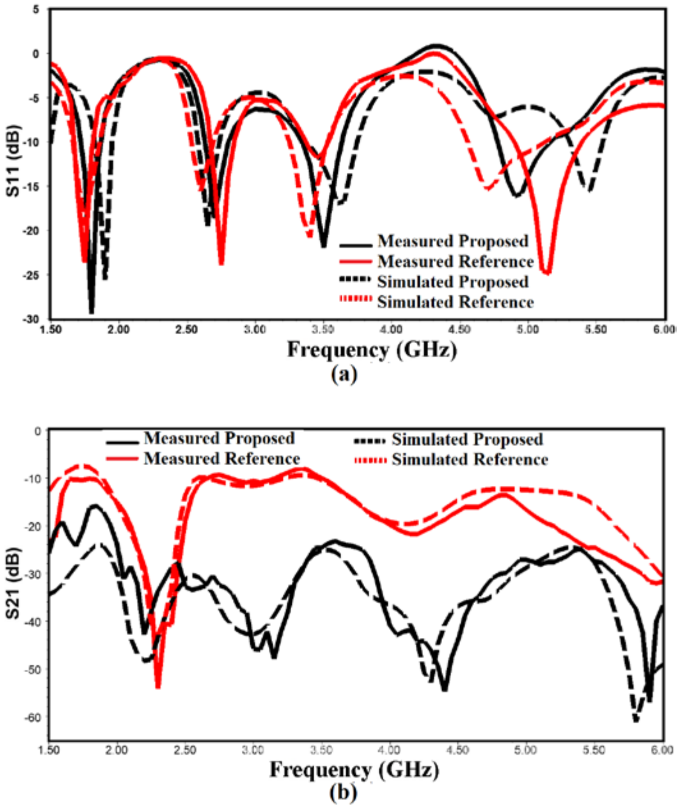


Fig. 5. Comparison of the simulated and measured scattering parameters for both reference and proposed antenna array. (a) Reflection coefficient (S_{11}) and (b) Transmission coefficient (S_{21}).

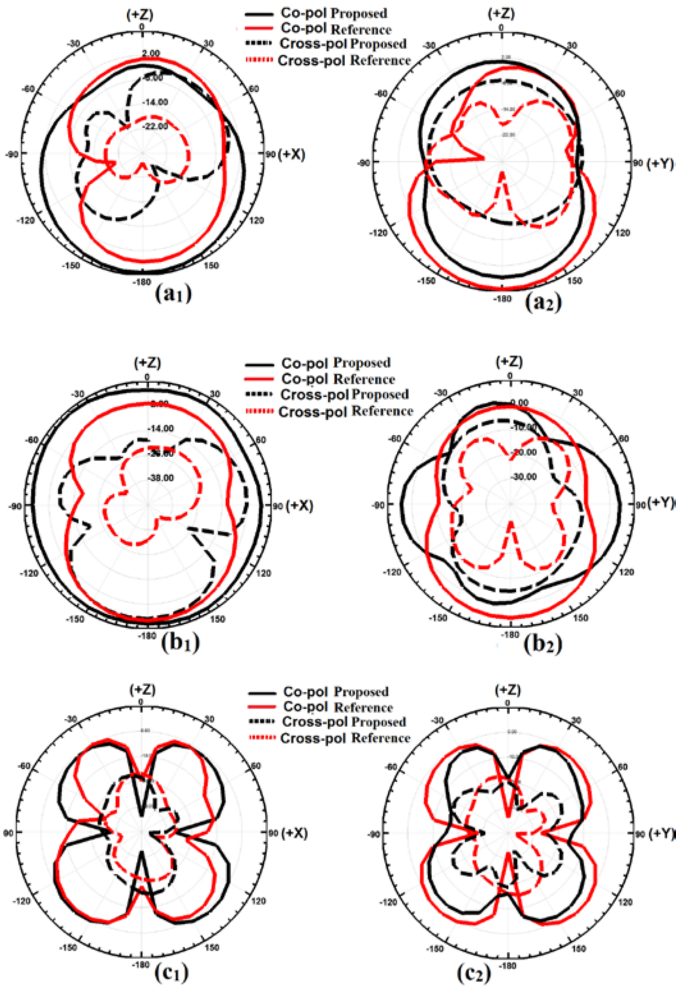
Fig. 5(a) shows the measured and the simulated return loss of impedance bandwidth (S_{11} < -10 dB) comparatively between multiband array. First; From the simulated return loss parameters; It is observed that the proposed antenna array have a good response for quad resonance to operate in many applications such as DCS mobile communication, Higher GSM band (1700-1800MHz), LTE 2500 band (2550-2700 MHz), WiMAX band (3300-3500MHz) and intended HiperLAN (4800-5200 MHz) with a return loss of -19 dB, -15 dB, -20 dB and -16 dB; respectively. A slight shift in each band (more shifting occurs at the third and fourth resonance) can be noticeable for the proposed antenna which can be compensated by slightly adjusting the slots width to keep the resonance frequency identical in both cases. This shift is caused by the capacitive coupling and extra inductance may be added that associated with the proposed wall (DWS) and shorting strips. However; for the proposed case and due to the lossy nature of these structure, return loss decreased from -19 dB to -25 dB and from -15 dB to -19 dB for the first, second band; respectively but increased from -20 dB to -16 dB for the third band and still maintain -15 dB at fourth band for the proposed case.

Mutual coupling between antenna elements can be determined from the transmission coefficients (S_{21} and S_{12} parameters); we observe a significant reduction in mutual coupling when hybrid isolation mechanisms are combined. The mutual coupling measured in terms of S_{12}, is -7 dB, -9 dB, -10.5 dB and -11 dB at approximately: 1.75 GHz, 2.6 GHz, 3.3 GHz and 5 GHz; respectively compared to -27 dB,-30.5 dB, -31 dB and -28 dB at same mentioned centre frequencies for the proposed array (as shown in Fig. 5(b)). However; an excellent isolation (S_{21}) of better than -27 dB has been achieved and more than 17 dB improvement over the reference antenna can be obtained in each band.

Moreover; a reasonably good agreement can be noticed between the measured and simulated plots although a slight difference between these results can be noticed. That may be attributed to some factors such as an inaccuracy in the fabrication process, variation in the quality of the substrate, and mismatch effect of SMA connectors. In all these measurements, one port is excited and the other terminated by the standard 50 Ω load.

B. Farfield Radiation Patterns

This section presents the study performed on the effect of far-field radiation patterns as a comparison between both cases (reference and proposed antenna). The two orthogonal-plane patterns of the antenna are demonstrated in Fig. 6. corresponding to the x-z and y-z principal planes.



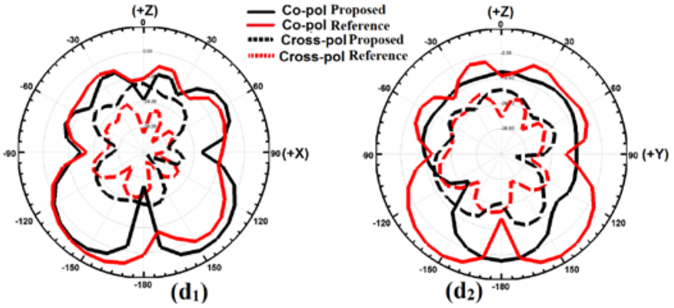


Fig. 6. The simulated radiation patterns: (a1) x–z plane, and (a2) y–z plane at 1.75 GHz; (b1) x–z plane, and (b2) y–z plane at 2.6 GHz; (c1) x–z plane, and (c2) y–z plane at 3.4 GHz; (d1) x–z plane, and (d2) y–z plane at 5 GHz; respectively. With port 1 excited.(solid line: co-pol, dashed line: cross-pol, black colour: proposed, and red colour: reference)

Overall antenna radiation patterns are relatively stable across the multiband frequencies. However; no significant degradation of radiation patterns are noticed for both cases and nearly omnidirectional patterns at various multiband frequencies,. These plots were obtained with one antenna port excited and other port terminated with matched impedance, i.e. 50 Ω load. Besides, the simulated peak gain and antenna radiation efficiency at multiband frequencies are plotted in Fig. 7.

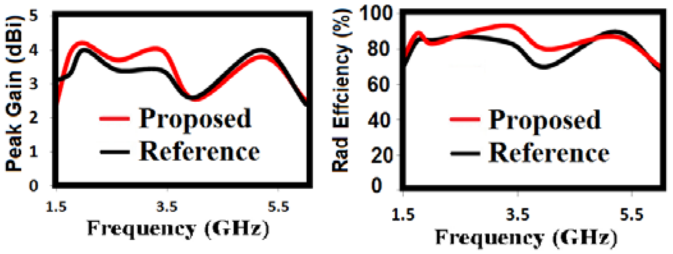
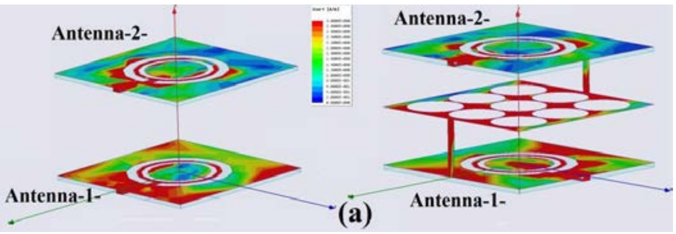


Fig. 7. Simulated peak gains (Left) and radiation efficiencies (Right) of the proposed antenna.

The achieved peak gain for the proposed antenna array varies between range 3.4–4.2 dBi , It is also observed that the radiation efficiency of the proposed antenna array is still high (more than 80%) in entire multi frequency bands which certifies that hybrid isolation methods does not have any noticeable effect on radiation characteristics.

C. Surface currents distribution

To further elaborate the effectiveness of these proposed structures (DWS and shorting strips), the degree of isolation in the proposed antenna can be observed by presenting surface currents distribution. HFSS software was used to generate images of the surface current distributions at multi frequency bands when first antenna is excited while the other is terminated with a matched load.



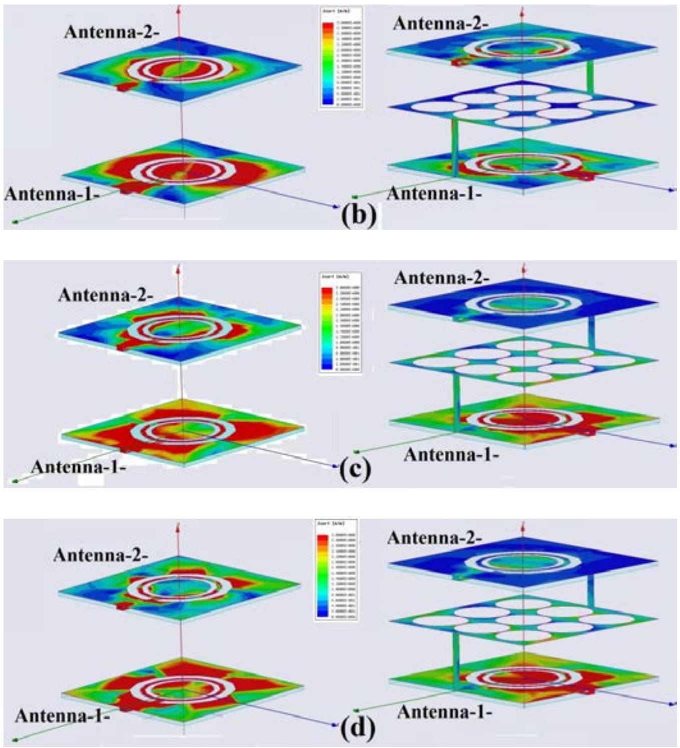


Fig. 8. Simulation of surface currents distribution on the reference antenna array (left side) and proposed antenna array (right side), when the first antenna is excited and the second antenna is terminated with a 50 load. at a frequency: (a) 1.75 GHz, (b) 2.6 GHz, (c) 3.4 GHz, (d) 5 GHz.

Fig. 8. illustrates the current distributions at the four operating frequency bands. It is observed that most of the current flow is absorbed by the wall (DWS) and the shorting strips, and thus it ameliorates the ports isolation between antennas. However; these structures play a significant role in providing the high isolation by preventing induced currents to reach the unexcited (none fed) antenna. The effect is same when second antenna was excited while first antenna was terminated with 50 Ω load.

D. Diversity performance

Envelope Correlation Coefficient (ECC) between antenna elements is another crucial parameter and one of the most important parameters as it indicates and evaluates the MIMO/diversity performance, because it is directly related with the antenna scattering parameters and may significantly degrade diversity system performance

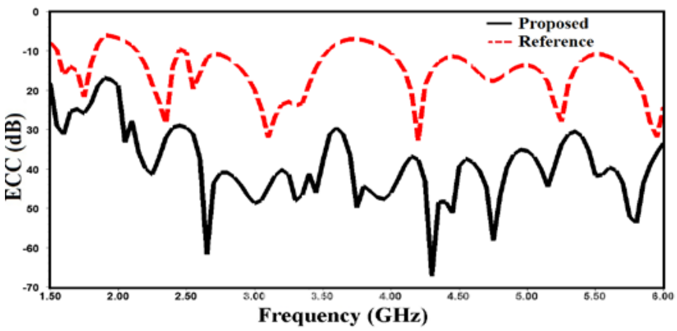


Fig. 9. Simulated envelope correlation coefficient of the reference antenna (dashed line-red colour) and proposed (solid line-black colour).

For dual (2×2) MIMO antenna system, the Envelope Correlation Coefficient (ECC) equation using the scattering parameters is given by [6].

$$\rho_{12} = \frac{|S^{*}_{11}S_{21} - S^{*}_{12}S_{22}|^2}{(1-|S_{11}|^2-|S_{21}|^2)(1-|S_{22}|^2-|S_{12}|^2)} \qquad (1)$$

In this work, ECC (ρ_{12}) can be calculated using (1) under some assumptions: ideal and uniform propagation multipath environment, antenna system is lossless, and one of the antenna elements is excited separately while keeping the other antennas matched terminated.

However; from the simulated results, the envelope correlation coefficient of the proposed antenna array is smaller (< -20 dB) compared that shown in the reference case (as shown in Fig. 9). This observation satisfies the diversity criteria and indicates for better behaviour over the entire multiband frequencies.

IV. COMPARISON WITH OTHER APPROACHES

As mentioned before; other methods have also been applied to reduce mutual coupling between various multi-band antenna arrays: defected or slotted ground plane technique, insertion of EBG structures, spatial and angular variations, and insertion of resonators or stubs…etc.

Table I. presents a summarised comparison of our proposed antenna array against other works previously reported and recently published in the literature; the proposed antennas show an excellent isolation maintaining on good compactness with reduced physical separation between arrays.

TABLE I. PERFORMANCE COMPARISON FOR DIFFERENT MULTI-BAND ANTENNAS

Ref. No	No. of Bands	S_{21} (dB)	Volume (W×L×H)	Space (λ_0)	Technique/ Complexity
[7]	Four	≤-12	60×100×0.8 mm^3	0.5	DGS/ Meduim
[8]	Two	≤-20	50×100×1.5 mm^3	0.4	EBG/ Complex
[9]	Two	≤-15	50×100×1.5 mm^3	0.4	MetaMaterial/ Complex
[10]	Two	≤-16	24×70×1.6 mm^3	0.5	Resonator/ Meduim
[11]	Two	≤-17	60×100×0.8 mm^3	0.4	Folding strips/ Meduim
[12]	Four	≤-14	60×100×1.6 mm^3	0.4	Spatial divers/ Meduim
[14]	Two	≤-13	60×90×1 mm^3	0.4	Naturalization lines/ Complex
Proposed	Four	≤-27	65×65×1.6 mm^3	0.25	Hybrid/ Simple

V. CONCLUSIONS

A high isolation quad-band printed slots array is presented in this paper. The proposed antenna constructed by concentric annular-ring slots fabricated on an inexpensive FR_4 substrate with total antenna dimensions of 65×65×1.6 mm^3 and fed by a 50-Ω microstrip line. A combination of isolation enhancement mechanisms has been presented and proposed for reducing the mutual coupling effects between the closely packed antenna elements, relatively straightforward and easy in implementation. Design and simulations are conducted using HFSS software version 17.0, a precise performance study involving isolation, radiation patterns, and surface current density distribution, were performed to identify the significance of the hybrid isolation enhancement mechanisms. A prototype of the proposed antenna array has been fabricated, measured and the idea has been verified. A good agreement is observed between the measured and the simulated results that demonstrate the success of the suggested design topology. Finally; the proposed antenna has been compared with other pervious works in terms of the mutual coupling level, geometric size and an implementation complexity. All results indicate that our proposed antenna array has more advantages than other suggestions in points of these criteria and it can be an excellent candidate in the multiband applications for some portable devices using MIMO/diversity systems.

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