Design of a Compact UWB-MIMO Antenna with Isolation Enhancement through Extended Elliptical Ground Plane

Dalal Zahaf, Soufiane Tebache, Abderrahim Kouar, Samy Labandji, and Ali Mansoul

Abstract- This paper deals with the design of a Multiple Input Multiple Output (MIMO) antenna for UWB applications. It is composed of two identical radiating elements (parallel monopoles) symmetrically arranged on a FR-4 substrate. The monopoles are closely spaced (about 0.2λ, center to center). A decoupling mechanism based on vertical extension of the Ground plane with elliptical edges (stub) allows to achieve high isolation (>20 dB). Further, the designed system presents good diversity performance, as the obtained Envelope Correlation Coefficient is less than 0.01. The antenna array is compact (36×30 mm^2), with ultra-wide operating frequency range (2.6 to 10.8 GHz). Simulations and measurements demonstrate good agreement. The obtained results make the proposed structure a good candidate for any UWB applications and modern wireless communications systems thanks to its wide frequency band, compactness and performance.

***Keywords-* UWB, Antenna array decoupling, MIMO systems, Elliptical Ground Plane.**

NOMENCLATURE

MIMO	Multiple Input Multiple Output.
UWB	Ultra Wideband.
ECC	Envelope Correlation Coefficient .
CST	Computer Simulation Technology.

I. INTRODUCTION

With the increasing demand for connectivity to multiple wireless systems and the need to transmit data at high speed, the ultra-wideband (UWB) standard (3.1 to 10.6 GHz) was considered to be key solution as it has a very high data rate, low power consumption and low cost [1]. Despite all these advantages, the UWB standard suffers from several constraints such as short range due to fast signal fading and multipath [2], and inter-symbol interference (ISI). Multi-Input Multi-output (MIMO) technology has been introduced to combine with the UWB standard due to the advantages of achieving higher range, reducing multipath fading, eliminating interferences and providing higher channel capacity [3].

Lot of researchers have devoted tremendous efforts to tackle the MIMO challenge, as this kind of designs is highly constrained with compact size, given the limited space in mobile devices leading to the increase of mutual coupling between adjacent radiators. Consequently, the overall antenna array performances are severely degraded [4].

To overcome mutual coupling task, several techniques have been proposed in the literature such as neutralization line (NL) [9], defected ground structure (DGS) [5], decoupling mechanism network (DMN) [10], electromagnetic band gap (EBG) [6, 7, 8], parasitic elements [11, 18] etc.

In this paper, a printed two element UWB antenna for MIMO systems is proposed. The design is compact with small size of 36× 30 mm^2 and small antenna spacing of about 0.2λ. We apply to the array a decoupling technique based on vertical extension of the ground plane that acts as a stub. The latter provides in the overall operating band an isolation higher than 20 dB. Simulation and measurement of ECC, DG and radiation pattern confirm the array diversity performance. The obtained results show the effectiveness of the proposed design and its attractive performance.

II. THE PROPOSED DESIGN

The design is composed of two identical monopoles symmetrically printed on the top layer of a FR-4 substrate (dielectric constant=4.4, thickness=1.6 mm, and tangent loss=0.02) and closely spaced (0.2λ), where λ refers to the free space wavelength evaluated at the lower frequency of the operating band (Fig. 1). Dimensions are optimized by using CST Microwave Studio and the overall size of the design is 36 × 30 × 1.6 mm^3. 50-Ohm input ports fed the antennas.Before decoupling, the antenna array is carefully studied and analyzed. Fig. 2 illustrates the simulation results of the S- parameters (S21 and S11).

Manuscript received May 21, 2022; revised July 2, 2022.

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Digital Object Identifier (DOI): 10.53907/enpesj.v2i1.94

It is noticed that the monopoles operate from 2.6 to 9.2 GHz (S11 <10 dB) with high mutual coupling of about 5 to 10 dB. The high coupling is due to the close proximity of the two monopoles (< 0.5λ).

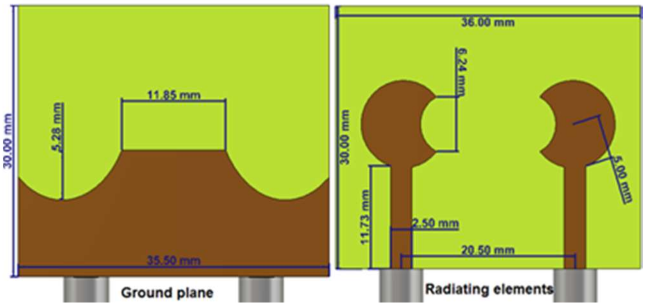

Fig. 1: Proposed antenna Geometry before decoupling.

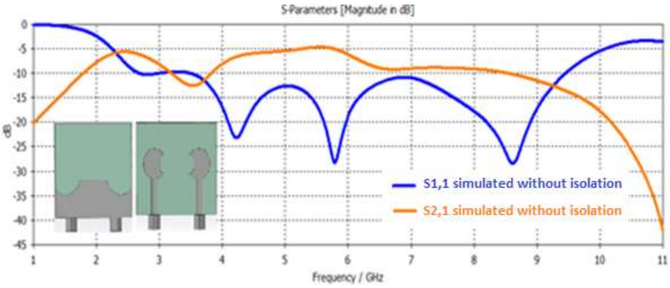

Fig. 2: S-parameters of the proposed antenna before decoupling.

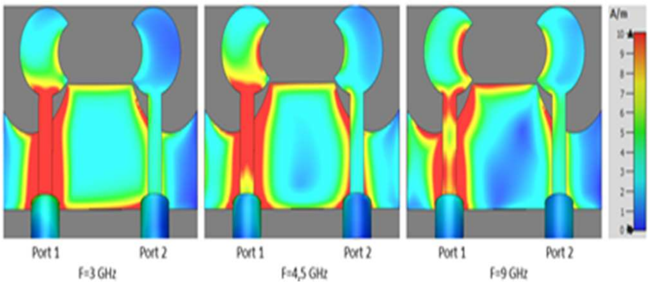

Fig. 3: Current distribution before decoupling (Port 1 excited).

Next, the Port 1 of the proposed antenna is excited and its Port 2 terminated with a 50-Ohm load. In Figure 3, the CST tool analyzes the surface current distribution of the designed antenna before decoupling at 3, 4.5 and 9 GHz. One observes high-density current flows from port 1 to port 2. The latter confirms the above S parameter results and shows the strong coupling between the two elements over the considered frequency band.

III. DECOUPLING MECHANISM OF THE PROPOSED ANTENNA ARRAY

A. Mechanism description

To solve the coupling problem, we try to find a method to trap surface currents flowing between the two ports (port 1 and port 2). Figure 4 depicts the proposed technique. A vertical extension of the ground plane with elliptical edges is added in the middle of the array ground plane. As seen in Fig. 4, the shape of the ground plane extension (stub) is optimized to operate in wide frequency range with enhancement of the antenna isolation.

B. Simulation results and discussion

The simulation results of the S parameters are illustrated in Fig. 5. After decoupling, it is noticed that the monopoles demonstrate a good impedance matching with weak mutual coupling (S21 ≤ -20 dB) in the frequency band of 2.6 to 10 GHz. In order to check the effectiveness of the proposed decoupling mechanism, current distribution is analyzed as well. As seen in Fig.6, the elliptical slots etched in the ground plane trap the current on their perimeter. As they behave like a microstrip line terminated with an open circuit, hence they prevent induced currents from flowing between excited ports.

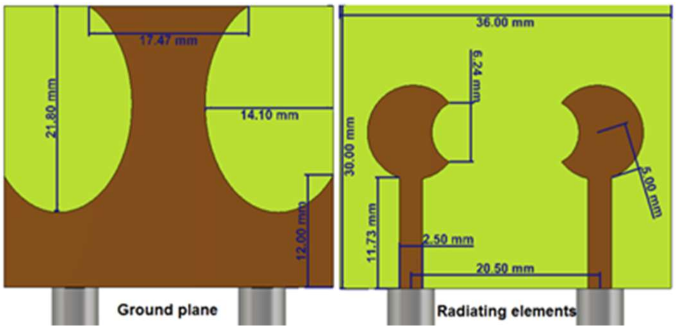

Fig. 4: Proposed antenna Geometry after decoupling.

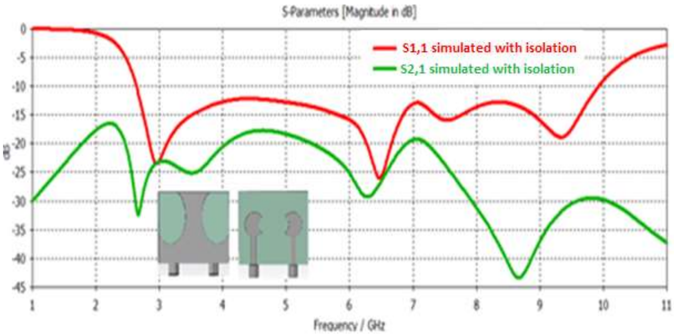

Fig. 5: S-parameters of the proposed antenna after decoupling.

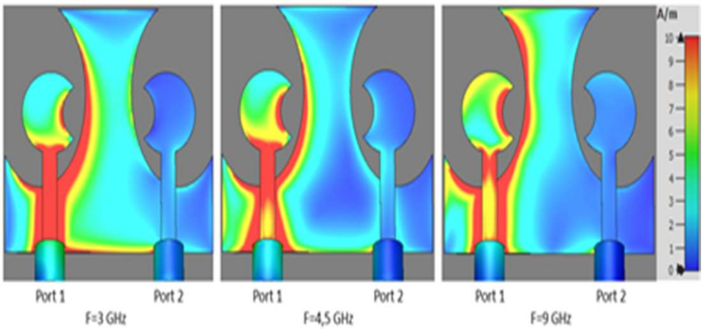

Fig. 6: Current distribution after decoupling (Port 1 excited).

The decoupled proposed antenna array is compared with respect to the coupled one through their S21 parameters in Figure 7. Hence, an improvement of about 15 dB is observed in the simulated transmission coefficient that indicates the effectiveness of the proposed decoupling mechanism.

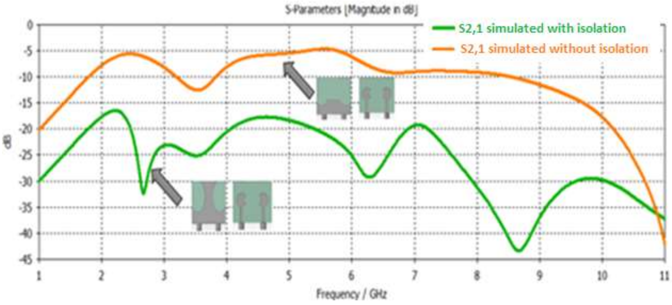

Fig. 7: Transmission coefficient (S21) with and without decoupling mechanism.

IV. MANUFACTURING AND EXPERIMENTAL DEMONSTRATION

The proposed design is manufactured and tested (Fig. 8).

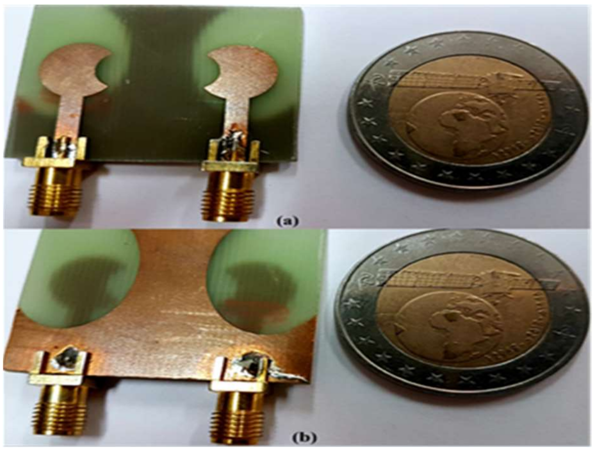

Fig. 8: Manufactured array antenna (a) Top layer (b) Bottom layer.

The simulated and measured S-parameters are shown in Figures 9 and 10. The obtaining results show an excellent match between the simulated and measured S-parameters in almost the entire UWB band as the reflection coefficients are less than -10 dB (see Fig. 9) with high isolation of more than 22 dB in the entire operating band (see Fig. 10). This agreement between simulation and measurement is obtained with slight discrepancies attributed to imprecision in the manufacturing process, instability of the substrate's relative permittivity, and SMA connectors mismatching. Figure 12 shows the radiation patterns of the proposed design evaluated both by the CST tool and by measurements in an anechoic chamber. Figure 11 shows the simulated and measured radiation patterns of the proposed decoupled antenna array at 3, 4.5 and 9 GHz in the planes H (Ø = 0°) and E (Ø = 90°). The radiation patterns are quasi-omnidirectional in the lower frequencies and more directional in higher ones which is due to the presence of the second antenna in closed proximity (behaves as a reflector). This behavior is an attractive feature as it helps in mitigating multipath effect and signal fading phenomenon.

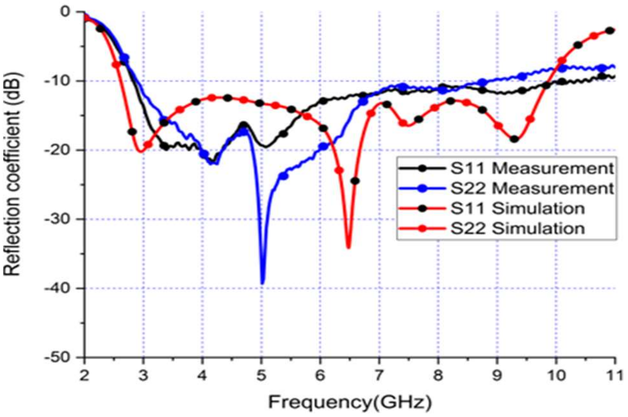

Fig. 9: Simulated and measured S11 and S22 parameters of the decoupled antenna array.

Moreover, acceptable agreement is achieved between simulation and measurement.

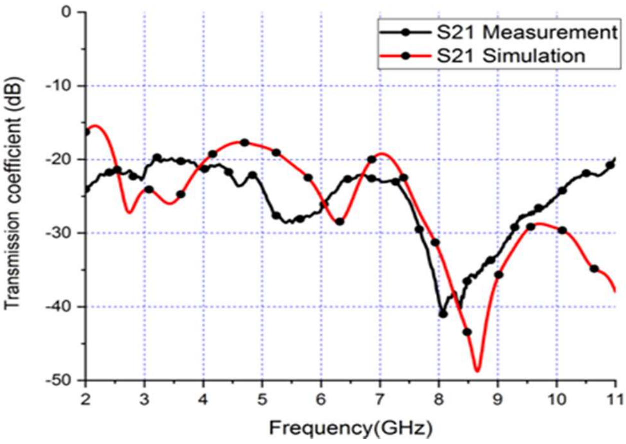

Fig. 10: Simulated and measured S21 parameter of the decoupled antenna array.

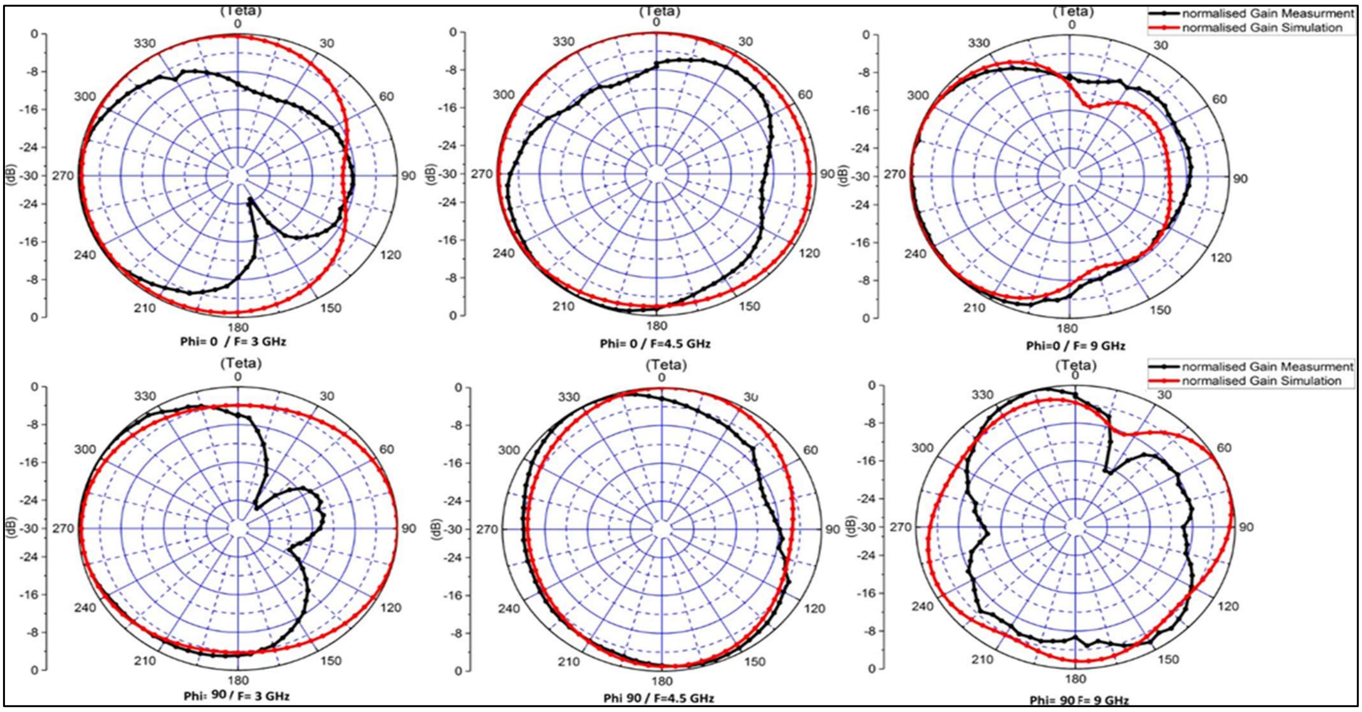

Fig. 11: Normalized simulated and measured radiation patterns in the plans E and H.

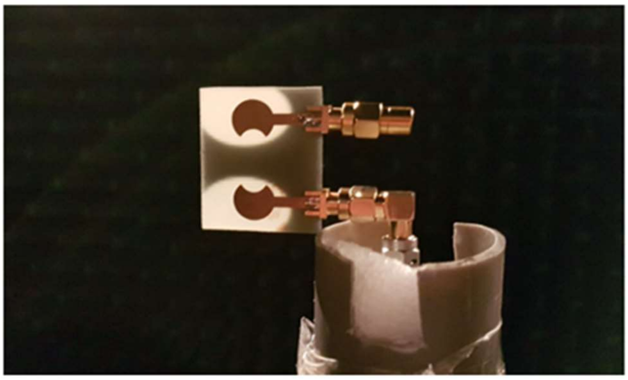

Fig. 12: Measurements in an anechoic chamber.

The Envelope Correlation Coefficient (ECC) is used as a metric for the evaluation of the diversity capabilities of the proposed MIMO antenna. The expression of this coefficient is given in equation (1) and measures the similarity between the received signals from the two Ports of the antenna array [4, 13].

$$\mathrm{ECC} = \frac{|S_{11}^{*}\,S_{12} + S_{21}^{*}S_{22}|^{2}}{\left(\left(1-\left(|S_{11}^{2}|+|S_{21}^{2}|\right)\right)\left(1-\left(|S_{22}^{2}|+|S_{12}^{2}|\right)\right)\right)} \qquad (1)$$

An ECC value of less than 0.5 is usually considered as acceptable in the design and evaluation of the mutual coupling between antennas [12].

The ECC results of our measured and simulated proposed antenna array are shown in Figure 13. The simulations and the measurements are in good agreement. The obtained measured ECC is close to zero (less than 0.01). This confirms the effectiveness of our achievement.

V. COMPARISON WITH RELATED WORK

A comparative study between our proposed UWB-MIMO antenna with respect to recent work is carried out and presented in Table 1. The comparison is based on various criteria such as bandwidth, mutual coupling reduction, size, design complexity and isolation technique. As a result, one can notice that the proposed design demonstrates outstanding features due to its high isolation, wide bandwidth, compact size, simplicity, low correlation and good diversity performances. Hence, the two antenna array can be good candidate for UWB portable devices.

Table. I
COMPARISION WITH RELATED WORK

Reference	Band Wide (GHz)	Size (mm)	Isolation (dB)	Spacing (λ)
[14]	2.8-10.1	55×34	≥17	0.27λ
[15]	3.1-5	35×16	≥22	0.15λ
[16]	4.4-10.7	35×46	≥17	0.19λ
[17]	4.4-9.5	36×40	≥15	0.2λ
Our work	2.6-10.8	36×30	≥22	0.2λ

VI. CONCLUSION

This paper proposed a new compact UWB-MIMO antenna. The proposed two-monopole array has attractive performance thanks to the simplicity of its structure and its high radiator isolation of about 22 dB. The decoupling mechanism considers the introduction of a vertical transition with elliptical edges in the GND plane allowing trapping currents from flowing between the antenna ports. The system can operate in very wide frequency range extending from 2.6 to 10.8 GHz. Moreover, the structure is compact as it is only 36×30×1.6 mm^3 PCB size which makes the design an attractive candidate for next wireless portable devices.

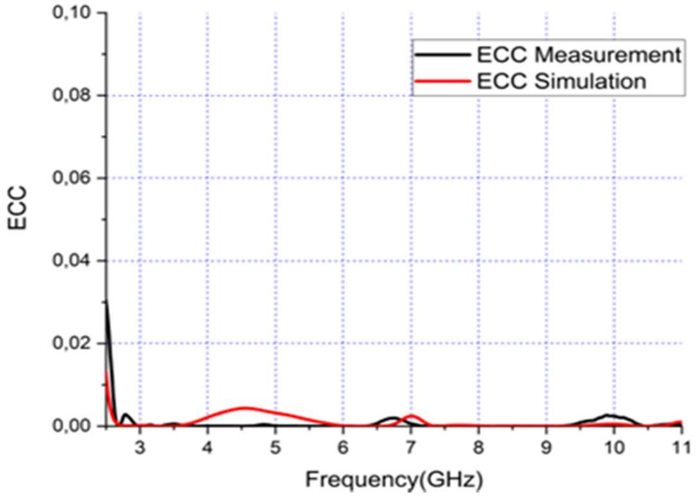

Fig 13: Envelope Correlation Coefficient (ECC) versus Frequency.

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