A Small Footprint Ultra-Wideband Multiple-Input Multiple-Output Antenna

Muhammad Saeed Khan, and Antonio-D.Capobianco
Department of Information Engineering
University of Padova Via Gradenigo 6/b, 35131 Padova, Italy
Email: khan@dei.unipd.

Sajid Asif, Adnan Iftikhar and Benjamin D. Braaten
Department of Electrical and Computer Engineering North Dakota State University
Fargo, ND 58102 USA
Email: benbraaten@ieee.org

Bilal Ijaz and Muhamad Farhan Shafique
COMSATS Institute of Information Technology,
Islamabad, 45000, Pakistan.
Email: bilal.ijaz@comsats.edu

***Abstract*— A compact planar Ultra-wideband Multiple-input Multiple-output antenna with two identical monopoles is presented in this paper. These monopoles are kept very close to each other at a distance of 5.5mm. Wideband isolation is obtained over the complete spectrum with a novel decoupling structure attached to the ground plane composed of an inverted y-shaped stub and a combination of horizontal and vertical strips attached to each other. The analysis of the antenna performance with and without the decoupling structure is provided to demonstrate the effectiveness of the proposed decoupling structure. The proposed antenna measures only 43×28 mm^2 and it is suitable for small handheld devices and future technologies based on UWB-MIMO.**

I. INTRODUCTION

Ultra-Wideband (UWB) technology has gained significant attention of researchers as a future technology owing to its intrinsic ability of interference immunity and potential of providing very high data rates. However, the conventional UWB technology faces the challenges of meeting demands for a gigabit data link due to insufficient throughput, hence to enhance the data rate Multiple-Input Multiple-Output (MIMO) techniques have been incorporated with UWB technology. MIMO technology has been used widely to increase the channel capacity of the system without using additional power or bandwidth at the transmitter end [1]-[3]. The basic concept of MIMO/diversity is to use multiple antenna elements for transmitting or receiving signals with different fading characteristics. However, installing multiple antennas on a compact portable or handheld device causes strong mutual coupling which results in degradation of system performance. Therefore, the basic objective of a UWB diversity system is to achieve wideband characteristics along with high port isolation, as witnessed in the literature in recent years. In [4] a folded Y-shape structure is used to decouple the antenna elements. In [5]-[6] stubs have been used to enhance the isolation. In [5] stubs have been inserted on the ground plane while in [6], a structured ground plane was designed to increase the isolation. Some other techniques involved a T-shaped reflector between two monopoles, cone shaped elements with a Defected Ground Structure (DGS) and parasitic elements on the back side of the radiators [7]-[9]. Moreover, the pattern diversity is also used in [10]-[11] to attain high isolation among radiating elements. In [12]-[14] polarization and pattern diversity is achieved using perpendicular feeding directions. A tree like structure has been introduced to enhance the wideband isolation in [15]. All of these techniques have trade-offs between bandwidth, size, antenna performance and antenna efficiency.

In this work, an UWB diversity antenna with a bandwidth from 2.5 to 11GHz is presented. It has a compact size of 28 × 43 mm^2, is about 10.5% smaller than the one proposed in [6] and is 12.5% smaller than the one proposed in [9]. The proposed antenna system has also less gain variation, when compared to the antenna presented in [6]. Two monopole radiators with a micro-strip feed are placed side-by-side. The ground planes of both radiators are connected with an inverted y-shaped stub to improve the matching. Finally three vertical and horizontal strips are connected to the ground planes to enhance the isolation and wideband characteristics of the proposed antenna array. It is very challenging to achieve a wide bandwidth of approximately 126% within compact design dimensions and retaining the antenna efficiency. It was especially considered that the patch antennas were not modified unlike previously reported more compact designs to ensure high antenna efficiency.

II. ANTENNA DESIGN PROCEDURE

The proposed design is finalized in three stages. The final geometry and dimensions of the proposed UWB-MIMO antenna are depicted in Fig.1. Initially a monopole is designed with a partial ground plane to achieve ultra wide bandwidth. The radiator is fed with a micro-strip line having a stepped impedance transformer. The arc shaped feeding edge of the patch is designed to ensure impedance matching over the complete band of interest. In the second design phase another monopole is placed on the side at a distance of 5.5 mm resulting in a strong mutual coupling. The ground plane of these monopoles is connected through an inverted y-shape stub. Finally three vertical and three horizontal strips are attached to the main stub. The layout of the ground planes is illustrated in Fig.2 and achieved results are plotted in Fig.3.

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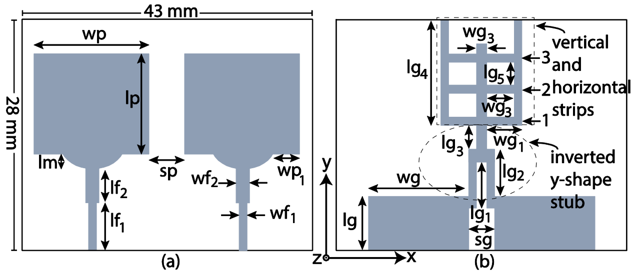

Fig. 1. Layout of proposed design (a) top view (b) bottom view. Dimensions are: *wp*= 18 mm, *lp*= 12.2 mm, *wp1*= 4.5mm, *lm*= 2.1 mm, *wf1*= 1mm, *wf2*= 2 mm, *lf1*= 5.8 mm, *lf2=4.07* mm, *sp*= 5.5mm, *wg*= 15.5 mm, *lg*= 6.25 mm, *sg*= 4 mm, *wg1*= 5.5 mm, *wg2*= 4.5 mm, *wg3*= 1.5 mm, *lg1*= 5.75mm, *lg2*= 6.05 mm, *lg3*= 3.2 mm, *lg4*= 12.5 mm, *lg5*= 3 mm.

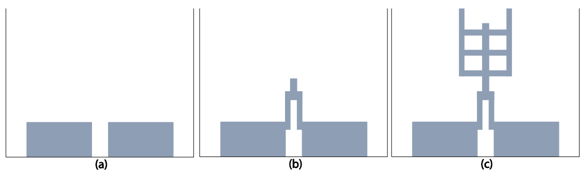

Fig. 2. Design phases of ground planes (a) separated ground planes, (b) inverted Y-shaped stub, (c) horizontal and vertical strips.

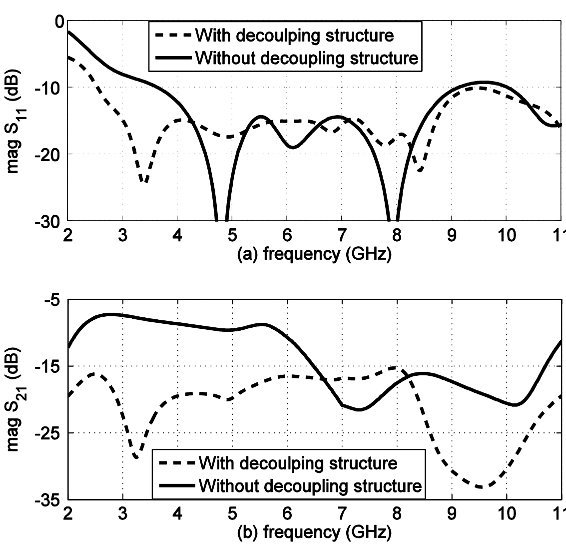

Fig. 3. Simulated response (a) reflection co-efficient (b) mutual coupling with and without decoupling structure.

When the ground planes of both radiators were connected through an inverted y-shape stub having a total length of 9.25 mm (l_{g2} + l_{g3}), a current path was established between the two ground planes. These currents are out of phase to the current induced on the ground plane at lower frequencies resulting in better isolation. Later on when a horizontal strip (labeled as 1 in Fig.1) was connected to the inverted y-shaped stub, it suppressed the coupling around

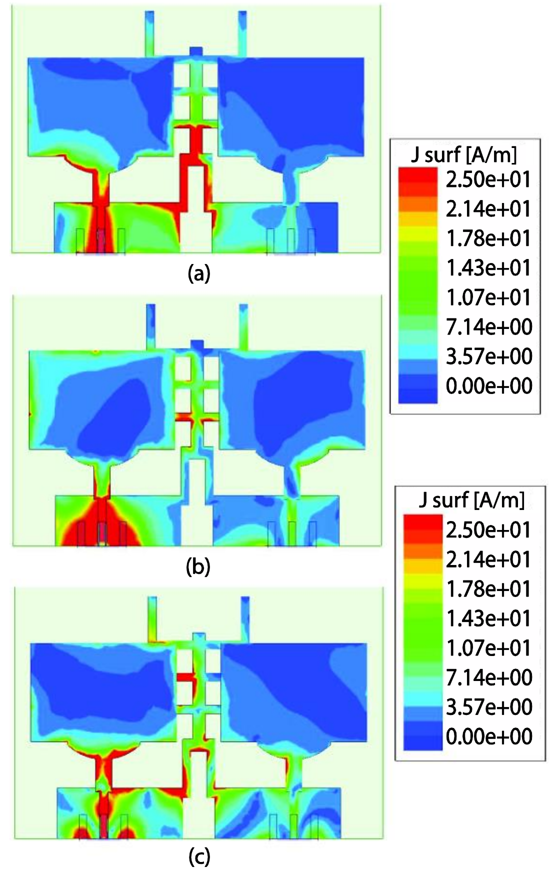

Fig. 4. Surface current distribution at (a) 3.2 GHz, (b) 6.5 GHz and (c) 9.7 GHz.

the 6 GHz band. Altering the ground plane resulted in an impedance mismatch which was compensated by attaching a vertical strip with width w_{g3} attached to the middle leg of the inverted y-shaped stub. In a similar way two more horizontal strips (labeled as 2 and 3 in Fig.1) were attached to improve the isolation and vertical strips with length l_{g4} to compensate for impedance mismatch. Fig.3. shows the overall improvement in the S-parameters with the use of the proposed decoupling structure.

The decoupling structure as a whole acts as a LC band stop filter. The gaps between the strips produce capacitance while the length of the strips introduces inductance [16]. This filter suppresses the current and reduces the mutual coupling among the antenna elements. To further elaborate the effects of the decoupling filter, the structure surface current distribution at different frequencies is plotted and is shown in Fig. 4. As described earlier the inverted Y-shaped stub improves the response below 4 GHz which is also indicated in Fig. 4 (a) where the maximum intensity of the current is on the inverted y-shaped stub. In Fig. 4 (b and c), the maximum current intensity is on the vertical strips which are attached to the horizontal strips. These strips also provide an extra path to the currents with variable phases to compensate the induced current on the neighboring ground plane in the middle and higher frequency bands to reduce the mutual coupling at middle frequencies [9].

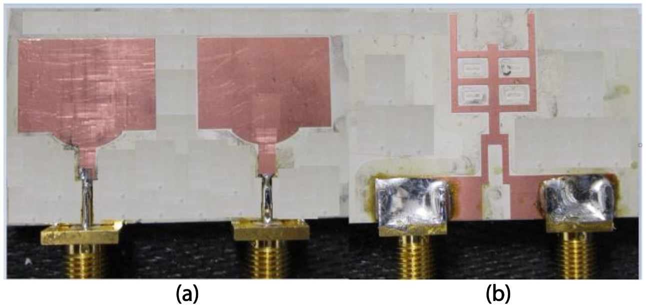

Fig. 5. Photograph of proposed UWB-MIMO antenna array (a) top side (b) bottom side.

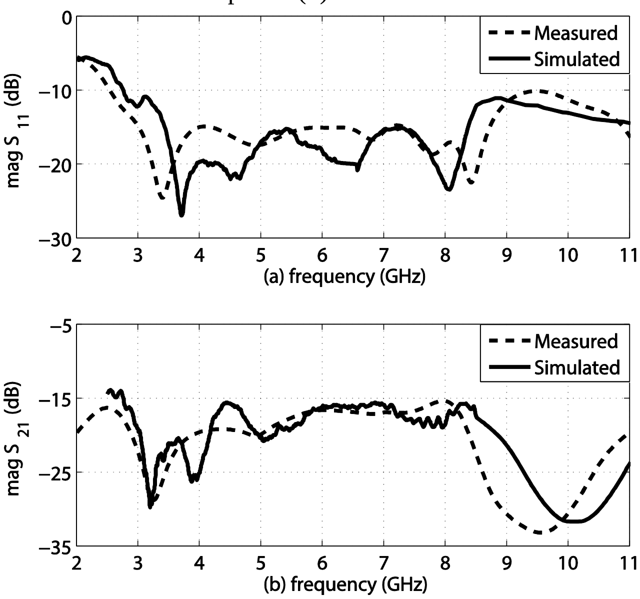

Fig. 6. Simulated and measured s-parameters of the UWB-MIMO antenna array.

III. Fabrication and Measurements

The material used for the fabrication of prototype was Rogers TMM4 laminate as shown in Fig. 5. The substrate was 1.52mm thick with a dielectric constant of 4.5 and loss tangent 0.002.

A. Scattering Parameters

The measurement results were taken from a PNA-X N524-2A network analyzer. A good agreement between the measured and simulated results has been observed, as presented in Fig.6. A slight shift in frequencies is due to the fabrication imperfection and wideband nature of the design. However, the return loss in the complete spectrum is less than 10 dB and the isolation is also higher than 15 dB.

B. Far-Field patterns, Gain and Efficiency

Far-field patterns of the proposed antenna system were calculated using commercially available finite element method-based electromagnetic simulation software (HFSS) [17] and measured in an anechoic chamber as well. The radiation patterns at 3.2, 6.5 and 9.7 GHz were measured in

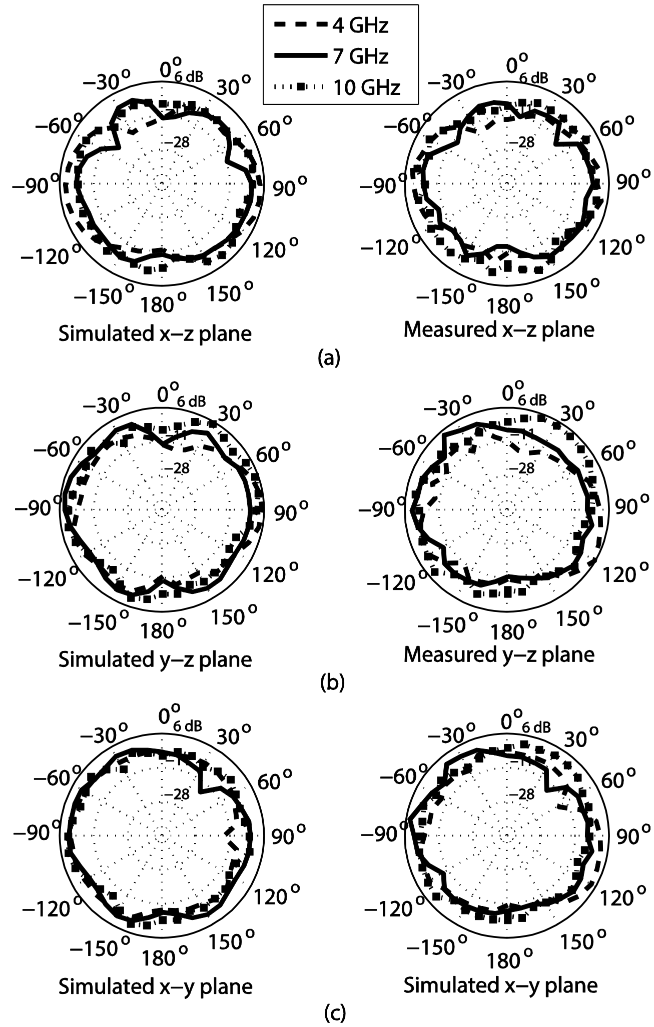

Fig. 7. Simulated and measured radiation patterns at 3.2 GHz, 6.5 GHz and 9.7 GHz, in the (a) x-z plane, (b) y-z plane and (c) x-y plane.

the x-z, y-z and x-y planes. These measured and simulated patterns are plotted in Fig. 7 for comparison. The patterns of the proposed antenna are different from traditional monopoles due to the presence of the nearby radiator and decoupling structure. During the measurements, port 1 was excited and port 2 is terminated with a 50 Ω load.

The results in Fig.8 show the comparison of the simulated and measured peak gain over the complete spectrum. The overall gain variation was less than 2.4 dBi with a peak gain of 5.8 dBi and minimum gain of 3.4 dBi, these measured characteristics of the proposed MIMO system ensured UWB functionalities over the complete spectrum.

Due to the presence of the proposed decoupling structure, potential effects on the efficiency can arise. The total efficiency (taking into account radiation efficiency as well as return loss) is plotted over the complete spectrum in Fig.9. The total efficiency was above 85% which showed that the decoupling structure has not deteriorated the efficiency of the proposed antenna.

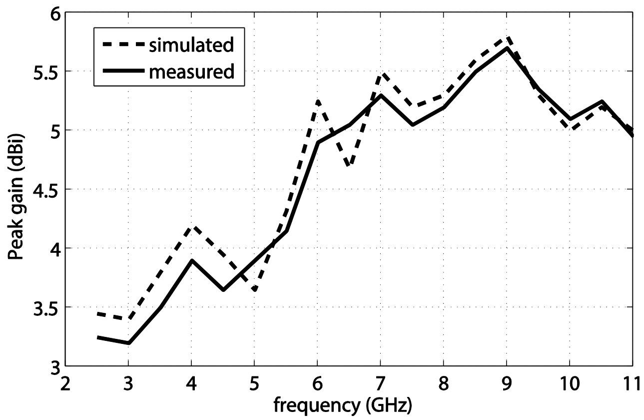

Fig. 8. Simulated and measured peak gain variation over the complete spectrum.

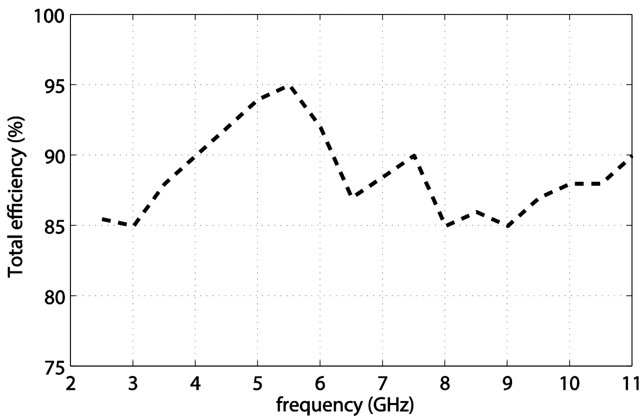

Fig. 9. Simulated total efficiency over the complete bandwidth.

IV. Time Domain Analysis

To check the time domain performance of the proposed antenna system, a pair of identical antenna arrays were fabricated and placed face-to-face at a distance of 10 cm and the group delay was measured. For the setup, one port of each array was connected to the network analyzer while the other was terminated with a matched 50 Ω load. The group delay measurements are shown in Fig. 10 over the complete spectrum. The group delay variations were less than 400 ps in the complete UWB band, which is an acceptable level for ensuring low pulse distortion.

V. Diversity Performance

Diversity performance of MIMO antenna systems can be analyzed from the scattering parameters as well as from the far-field patterns. For a two port antenna system, the envelope correlation coefficient for a uniform rich scattering multipath propagation environment is derived using the scattering parameters, as proposed in [18]. The envelope correlation calculated using the S-parameters is also verified through the far-field patterns assuming isotropic distributions in a uniform multipath propagation environment. A good diversity gain can

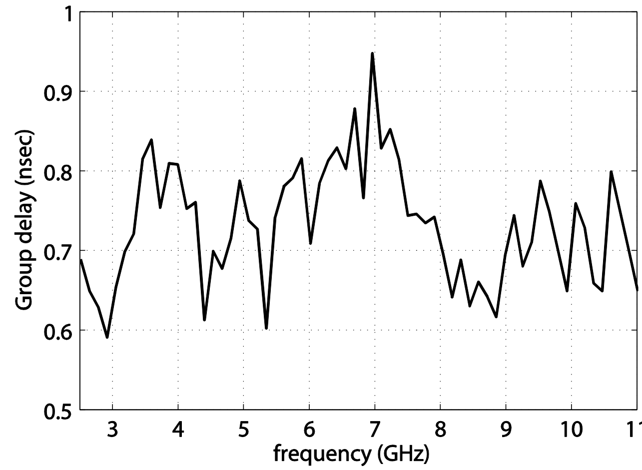

Fig. 10. Measured group delay over the complete spectrum.

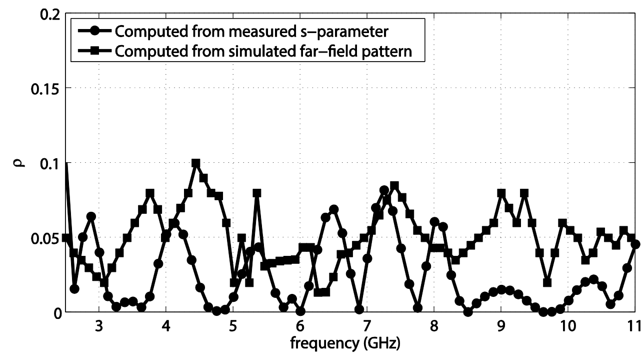

Fig. 11. Envelope correlation coefficient for uniform multipath propagation environment computed using measured S-parameters and simulated far-field patterns

be obtained when the ECC is less than 0.5 [19]. The measured correlation coefficients calculated from the scattering parameter and the simulated complex correlation coefficients, computed from the far-field patterns according to [20] by using commercially available simulator CST [21], are plotted in Fig.11. The correlation coefficients are less than 0.1 over the complete bandwidth which gives good channel behavior of this MIMO antenna. These values of ECC are dependent on the isolation characteristics; higher isolation gives lower ECC values and a good diversity gain. Without using the decoupling structure, when isolation was -7 dB, the calculated value of ECC from the S-parameters was 0.55, which is much higher than the calculated values from the measured S-parameters using the decoupling structure.

VI. Conclusion

A small footprint UWB-MIMO antenna with an effective decoupling structure has been presented. The decoupling structure is based on a wideband LC filter. Since the decoupling is achieved through a special structure connected to the ground plane instead of modifying the patch elements, the antenna efficiency remains high unlike previously proposed antennas where small radiating elements with various modifications resulted in reduced efficiency, hence low gain. Good agreements between simulated and measured results were observed. Reflection coefficients better than -10 dB and a mutual coupling better than -15 dB in the complete spectrum from 2.5 to 11 GHz was also shown. Furthermore, the correlation coefficient was less than 0.1 for this compact antenna of 43×28 mm^2. The compactness and wideband characteristic of the proposed antenna make it suitable for small handheld portable devices as well as for future UWB-diversity applications.

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