Electronically Reconfigurable WLAN Band-Notched MIMO Antenna for Ultra-wideband Applications

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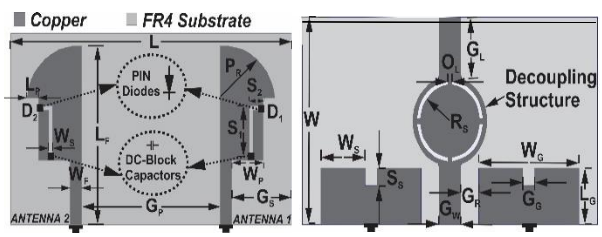
Abstract ─ A low-profile electronically reconfigurable WLAN band-notched dual port multiple-input multiple-output (MIMO) antenna design for ultra-wideband applications has been presented. Antenna elements exhibit good impedance match ($S_{11} \leq$ -10 dB) over entire ultra-wideband (3.1 to 10.6 GHz) spectrum. The decoupling structure is used to improve isolation (S_{12}/S_{21}) above 20 dB over entire UWB band. Moreover, reconfigurable band-notching is achieved by inserting PIN diodes along the inverted L-shaped slots, in each radiator. Notch at WLAN (5.5 GHz) frequency band is achieved by switching the PIN diode to 'OFF' state. The antenna design is fabricated as well as measured, and the results suggests that the proposed design with switchable WLAN band-notch characteristics is suitable candidate for ultra-wideband applications.

Index Terms ─ Isolation, multiple-input multiple-output (MIMO), PIN diodes, reconfigurable, ultra-wideband (UWB), WLAN band-notch.

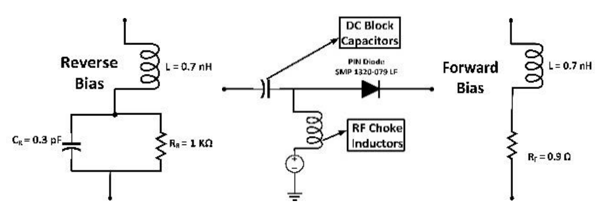
I. INTRODUCTION

Wireless communication technologies have gained much attention over last few decades. The prime focus of recent wireless technology is to use minimum resources, achieve high data rate and cause minimum interference to other existing wireless communication standards [1]. To achieve higher data rates and higher channel capacities, MIMO technology is integrated in UWB systems. However, a significant challenge in UWB-MIMO communication is the miniaturization of system. The unwanted mutual coupling is caused by miniaturization and hence the effectiveness of MIMO is compromised. Therefore, in order to provide decoupling between antenna elements, an efficient isolating/ decoupling structure is desired in MIMO systems. In existing literature, several MIMO antenna designs with decoupling structures have been reported to attain high isolation between antenna elements [2-3]. To achieve interference mitigation in UWB communication, several designs with band-notched characteristics have been reported in the existing literature [4-5]. However, these proposed antennas have permanent band-notching. For the sake of interference free communication, utilization of whole UWB spectrum may not be possible even if there is no conflicting narrow band system working in the close proximity. Therefore, for the improvement of the UWB system performance, antennas with reconfigurable/ switchable band notch performances are desirable [6-7].



(a) (b)

Fig. 1. Geometry of dual-port antenna system: (a) front view and (b) rear view.



(a) (b) (c)

Fig. 2. Equivalent circuit model of PIN diode: (a) case I, (b) biasing network, and (c) case II.

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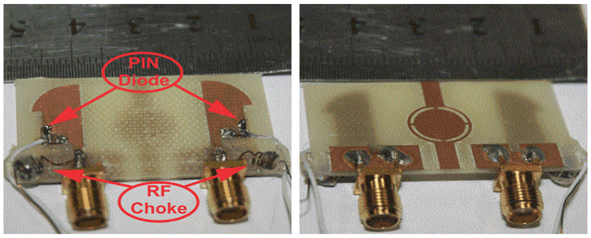

(a) (b)

Fig. 3. Fabricated design: (a) front view and (b) back view.

A miniaturized dual port MIMO antenna exhibiting electronically reconfigurable WLAN (5.1 - 5.8 GHz) band notch capability is proposed in this research for ultra-wideband MIMO applications. More than 20 dB isolation (S_{12}/S_{21}) is achieved among radiating elements for entire ultra-wideband using a decoupling structure. The analysis and optimization of these computationally intensive structures is performed using a full-wave Finite Element Method (FEM) based electromagnetic solver (Ansys HFSS™). The whole structure is enclosed in an air box with radiation boundary condition and the antenna is fed through a wave port excitation. In order to get realistic results of simulation, whole structure is simulated at once and no symmetric boundary has been adopted for MIMO antenna designs.

II. DESIGN CONFIGURATION OF ANTENNA

The geometric structure of proposed antenna is presented in Fig. 1. Antenna design is simulated and fabricated on a 1.6 mm thick FR4 substrate. The upper layer contains two radiators. Whereas, the partial ground and circular decoupling structure is placed on the back side of substrate. The decoupling structure as shown in Fig. 1 (b) contains defected circular ring. It is placed between ground planes to isolate the side-by-side placed antenna elements. The single UWB antenna element and two port UWB MIMO antenna with decoupling structure has been designed in HFSS using finite element method. MIMO design can be extended to four port by placing symmetrical two port MIMO antenna in front of designed MIMO antenna at appropriate distance. Appropriate decoupling structure is required to achieve isolated four port operation. The overall decoupling of more than 20 dB between MIMO antenna elements is achieved.

The optimized design parameters are shown in Table 1. All parameters of the design have known effect on the antenna response like the ground related parameters affect the impedance matching thus dictates the bandwidth. The parameters associated with the decoupling structure changes the mutual coupling. The parameters associated with the slot length and width change the notching frequency. All these parameters work in groups where one group achieves one single objective, thus co-optimization is not required making things simple and easy to tune. Therefore, no automated optimization method has been used and parameters were optimized manually around their optimum value through the simulator (High Frequency Structure Simulator).

The effective length of notching structure is required to filter out the desired frequency band. Notching at desired frequency bands can be obtained using equation (1):

$$f_r = \frac{c}{4L\sqrt{\varepsilon_{eff}}}. \quad (1)$$

An inverted L-shaped slot $L_{Total} = S_1 + S_2$ is created in main radiator of each antenna element. It provides WLAN (5.5 GHz) band notch characteristics. The current around the edges of slots reverses its direction causing anti-resonance at the desired notched frequency band. Moreover, to achieve the reconfigurable band notch functionality in UWB-MIMO antenna, PIN diode is embedded in the slot of each radiator, as shown in Fig. 1 (a). The purpose of PIN diode is to switch the UWB-MIMO antenna between ultra-wideband operation and WLAN band notch functionality. The PIN diode, D_1, as shown in Fig. 1 (a), controls Antenna 1 band notching. Similarly, D_2 diode control the band notching functionality of Antenna 2. The reconfigurable characteristics of proposed UWB-MIMO antenna have two operations as below:

Case I: When diode is forward biased or is in its 'ON State'. Antenna offers no notching behavior and UWB-MIMO antenna provides matching without any band notch.

Case II: When diode is reverse biased or PIN diode is in its 'OFF State'. Antenna eliminates the WLAN band from the UWB band and operates as a band notch antenna.

The PIN diode is first modeled in HFSS™ using lumped elements according to the equivalent model for Case I and Case II, as shown in Fig. 2. SMP 1320-079 LF PIN diodes have been used for switching. The diode has low reverse bias (zero volt) capacitance of 0.3 pF at above 10 MHz frequencies and low resistance of 0.9 ohms at 10 mA during forward bias operation. For the prevention of short circuiting in PIN diode biasing circuitry, each slot is connected with a 30 pF DC block capacitor as shown in equivalent circuitry of biasing network Fig. 2 (b).

III. RESULTS AND DISCUSSIONS

Antennas are fabricated on FR4 laminate, as shown in Figs. 3 (a) and (b). As the antenna elements are identical, impedance matching is similar for each element. The results are presented in Fig. 4. Result shows that both antenna elements are well-matched over entire ultra-wideband spectrum for Case I (diodes switched 'ON'). However, for Case II (diodes-switched 'OFF') proposed UWB-MIMO antenna provides WLAN (5.15-

5.825 GHz) band notching. The DC block inline SMA module has been mounted with VNA so no onboard DC block capacitor is installed. The RF choke is added to all elements. The effect of decoupling structure on isolation of antenna elements placed side-by-side, for both Case I and II, can be observed clearly in Fig. 5. The overall isolation with decoupling structure is better than 20 dB.

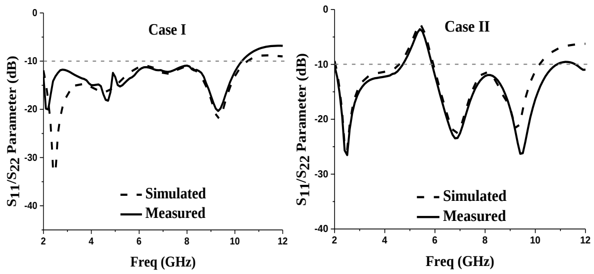

Fig. 4. Impedance matching of proposed prototype.

The effect of decoupling structure on isolation of antenna elements placed side-by-side, for both Case I and II, can be observed clearly in Fig. 5. The overall isolation with decoupling structure is better than 20 dB.

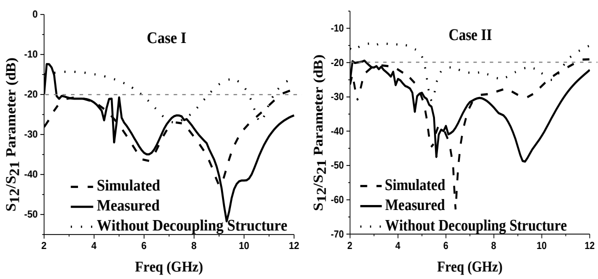

Fig. 5. Mutual coupling of proposed prototype.

Agilent N5242A PNA-X network analyzer is used for testing of proposed antenna design. Radiation patterns have been measured using Diamond Engineering setup in anechoic environment. The radiation patterns in E and H-plane of the proposed antenna (Case I and Case II) are observed at 5.5 GHz and 7 GHz and are plotted in Fig. 6. MIMO antenna system shows band notch characteristics for Case II. Therefore, in order to have good analysis of notched WLAN band, we observe gain characteristics of the proposed prototype. Figure 7 clearly depicts that the proposed antenna gives good gain results over whole UWB band except for the notched WiMAX band.

Channel Capacity Loss (CCL), Total Active Reflection Coefficient (TARC) and Envelope Correlation Coefficient (ECC) are important diversity parameters to analyze the performance of the proposed MIMO antenna. ECC can be calculated for different antenna topology (side-by-side) using equation (2):

$$\rho_e = \frac{\left|S_{ii}^{*}S_{ij} + S_{ji}^{*}S_{jj}\right|^2}{\left(1-|S_{ii}|^2 + |S_{ji}|^2\right)\left(1-|S_{jj}|^2 + |S_{ij}|^2\right)}. \quad (2)$$

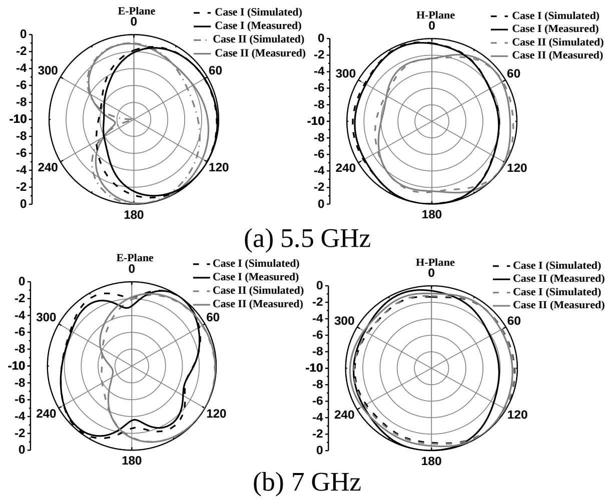

Fig. 6. Radiation plots: (a) 5.5 GHz and (b) 7 GHz.

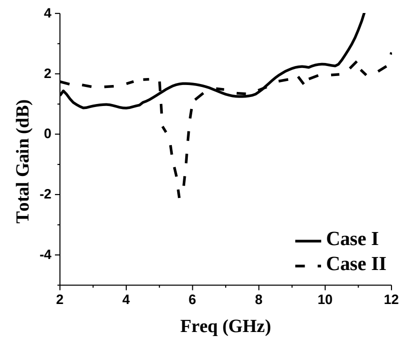

Fig. 7. Gain of proposed antenna.

Table 1: Optimized values of proposed antenna

Parameter	L	W	G_P	G_S	W_S	W_G
Value(mm)	40	23	19.8	8.5	6	13.5
Parameter	L_G	W_P	G_R	S_S	P_R	L_P
Value(mm)	6.25	4.5	2.45	2	7	1.65
Parameter	L_F	W_F	G_W	G_G	R_S	O_L
Value(mm)	21.4	1.6	3	1.6	4	0.5
Parameter	G_L	W_S	S_1	S_2	-	-
Value(mm)	6.7	0.5	4.4	1.2	-	-

Usually, an ECC value below -3 dB, TARC < 0 dB and CCL< 0.5 bits/sec/Hz in the operating band, is desired. As shown in Figs. 8 (a - c), the results are well within the allowable limits for both Cases (I and II). In Case II the CCL value at WLAN (5.15-5.825 GHz) band is above 0.5 bits/sec/Hz, because of the anti-resonant effect of band notching structure.

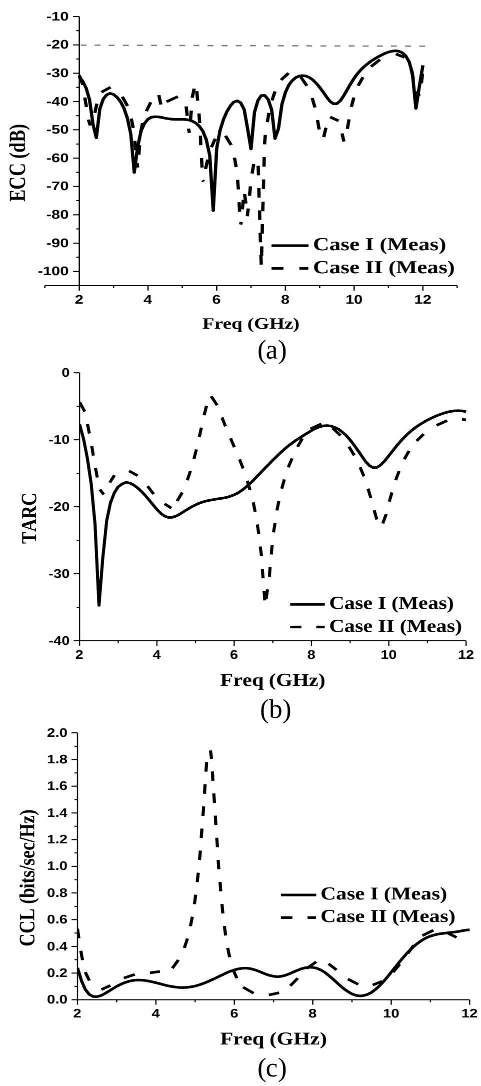

Fig. 8. MIMO/Diversity performance parameters: (a) ECC, (b) TARC, and (c) CCL.

Table 2: Comparison of proposed MIMO antenna with existing literature

Ref.	Isolation (dB)	No. of Ports	Antenna Dimension (mm^3)	Reconfigurability
[8]	> 15	2	50 x 82 x 1.6	No
[9]	> 15	2	40 x 30 x 0.8	No
[10]	> 20	2	35 x 35 x 1	No
Proposed antenna	> 20	2	40 x 23 x 1.6	Yes

IV. CONCLUSION

A miniaturized dual port MIMO antenna with electronically reconfigurable WLAN (5.5 GHz) band notch characteristics is proposed for ultra-wideband applications. The design operates over entire UWB band. Simple decoupling structure is used to achieve enhanced isolation. Diversity parameters are also within the allowed limits. More importantly simulated as well as measured results are in good agreement, suggesting that the proposed MIMO antenna design is suitable candidate for reconfigurable ultra-wideband application.

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