Compact Quad Element UWB-MIMO Antenna with Electronically Reconfigurable WiMAX Band-Stop Capability

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Abstract **─** Miniaturized four port multiple-input multiple-output (MIMO) antenna with electronically reconfigurable WiMAX band-stop capability is proposed for ultra-wideband (UWB) application. The elements of MIMO antenna system exhibit good impedance match (VSWR ≤ 2), while offering high ports isolation (S_{12} ≤ -20 dB) over the whole ultra-wideband spectrum. Moreover, reconfigurable band-notch capability at WiMAX (3.2-3.8 GHz) frequency band is achieved by switching the PIN diode to 'ON' state. The antenna is fabricated and measured as well, and the results suggest that the proposed antenna design with switchable WiMAX band-notch characteristics is a suitable candidate for UWB-MIMO applications.

Index Terms **─** Band-stop, multiple-input multiple-output (MIMO), reconfigurable, WiMAX.

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 [3-4]. To achieve interference mitigation in UWB communication, several designs with band-notched characteristics have been reported in the existing literature. In [1], inverted stubs added to radiator for interference mitigation at 5.8 GHz is reported. A circularly slotted notching structure is proposed in [2]. 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 [7-8]. PIN diodes are placed on stub at ground plane in [7] to notch WLAN frequency band, while in [8] PIN diodes are placed on the radiating patch in order to achieve reconfigurable band notch characteristics.

A miniaturized four port MIMO antenna exhibiting electronically reconfigurable WiMAX (3.2 - 3.8 GHz) band notch capability is proposed in this research for ultra-wideband MIMO applications. Isolation of more than 20 dB among all radiating elements over entire ultra-wideband band is achieved using a decoupling structure. For design and optimization of the antenna geometry, full wave electromagnetic simulations using Finite Element Method (FEM) have been carried out in Ansys High Frequency Structural Simulator (HFSS)™.

II. DESIGN CONFIGURATION OF ANTENNA

The geometric structure of proposed antenna is presented in Fig. 1. Antenna design is simulated and fabricated on a 0.8 mm thick FR4 substrate. The upper layer contains four radiating elements whereas the defected ground plane and decoupling structure is placed

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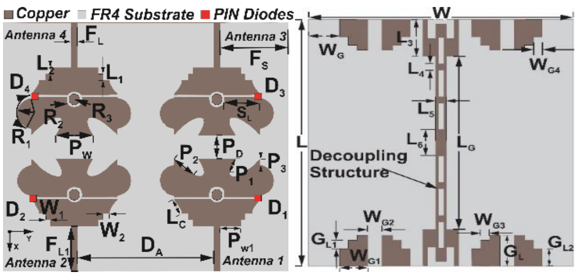
on the back side of substrate. The decoupling structure as shown in Fig. 1 (b) contains defected rectangular strip line. It is placed between ground planes to isolate the antenna elements placed in diagonal and side-by-side arrangement. The overall decoupling of more than 20 dB between MIMO antenna elements is achieved.



(a) (b)

Fig. 1. Antenna structure: (a) front view and (b) back view. L=26, W=30, P_W=3.9, R_3 =0.6, F_{L1}=4.7, L_5=1.2, R_2=0.8, P_D=2.5, W_G=3.5, D_A=14.4, L_6=2.8, G_L=3.2, L_1=0.65, P_1=1.2, W_{G1}=3.2, F_S=7.2, L_C=1.5, G_{L1}=1, L_2=0.7, P_2=2.7, W_{G2}=1.6, S_L=3.75, W_1=0.5, G_{L2}=1.8, L_3=3.8, P_3=0.6, W_{G3}=1, F_L=0.62, W_2=0.7, L_4=0.7, P_{W1}=2.2, W_{G4}=1, L_G=18.5, R_1=1.5 (parameters in mm).

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):

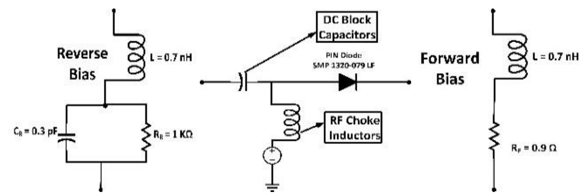
$$f_r = \frac{C}{4L_{Total}\sqrt{\varepsilon_{eff}}}. \quad (1)$$

Where, $L_{Total} = 2S_L + 2\pi R_2$ and 'C' is the constant of electromagnetic wave velocity. The calculated value of effective dielectric is $\varepsilon_{eff} \sim 3.1$. By putting values in equation, we get $f_r \sim 3.5$ GHz. An Ω-shaped slot is created in main radiator of each antenna element. It provides band notch characteristics at WiMAX 3.5 GHz. The current around the edges of slots reverses its direction causing anti-resonance at the desired notched frequency band. To show this effect, current density (*J-surf*) plots at 3.5 GHz with diodes switching (ON/OFF) is shown in Fig. 4. 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 WiMAX band notch functionality. The PIN diode, D_1, as shown in Fig. 1 (a), controls Antenna 1 band notching. Similarly, D_2, D_3 and D_4 diodes control the band notching functionality of Antennas 2, 3 and 4 respectively. The reconfigurable characteristics of proposed UWB-MIMO antenna have two operations as below:

Case I: When diode is reverse biased or is in its 'OFF State'. Antenna omits the WiMAX band notching behavior and UWB-MIMO antenna provides matching without any band notch.

Case II: When diode is forward biased or PIN diode is in its 'ON State'. Antenna eliminates the WiMAX 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. The whole biasing network has been fed through an in-line DC block module to prevent any damage to the network analyzer. The DC block is shown in Fig. 2 (b).



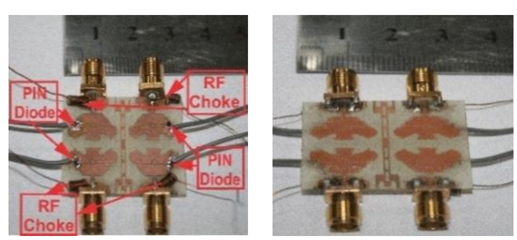
(a) (b) (c)

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

III. RESULTS AND DISCUSSIONS

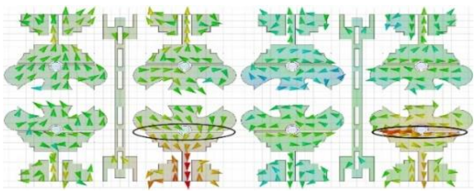
Antenna design is fabricated on FR4 laminate, as shown in Figs. 3 (a) and (b). Agilent N5242A PNA-X network analyzer is used for the measurements. As the antenna elements are identical, impedance matching is similar for each element. The results are presented in Fig. 5. Result shows that four antenna elements are well-matched over entire ultra-wideband spectrum for Case I (diodes switched 'OFF'). However, for Case II (diodes-switched 'ON') proposed UWB-MIMO antenna provides WiMAX (3.2-3.8 GHz) band notching. The RF choke is added to all elements.

To analyze the effect of switching on proposed antenna design, a characteristic mode analysis (CMA) is done in CST Microwave Studio [9]. In Case II, the variation of Mode 1 is clearly observed in Fig. 6. The curve of the characteristic angle associated to this mode presents a sharp slope, which verifies a sharp band notch behavior in this mode. Moreover, it may be noted that the resonant frequency lies at the center of the rejected WiMAX band, as desired.



(a) (b)

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



(a) (b)

Fig. 4. Surface current density *J-surf* at 3.5 GHz: (a) Case I and (b) Case II.

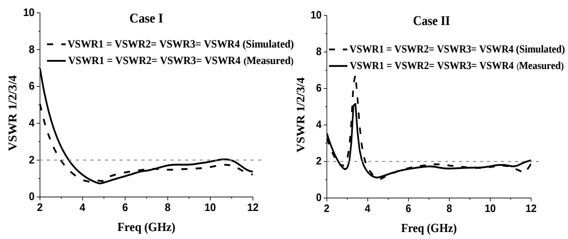


Fig. 5. Impedance matching of proposed prototype.

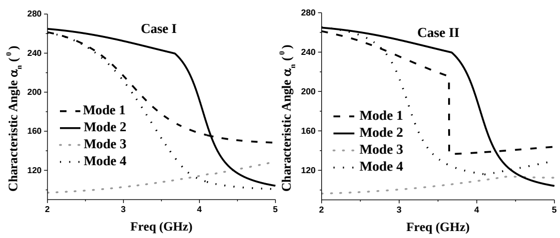
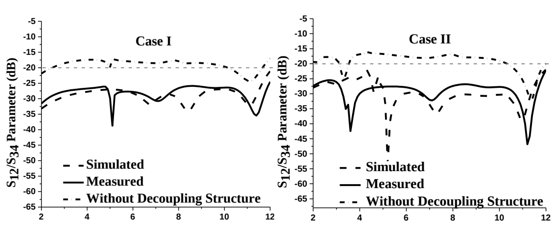
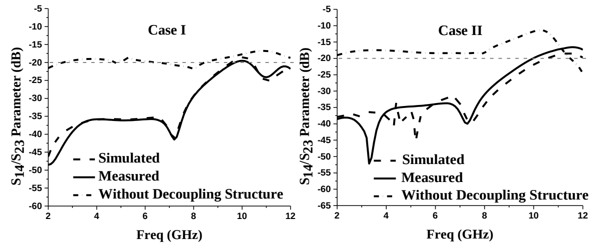


Fig. 6. Characteristic modes analysis.

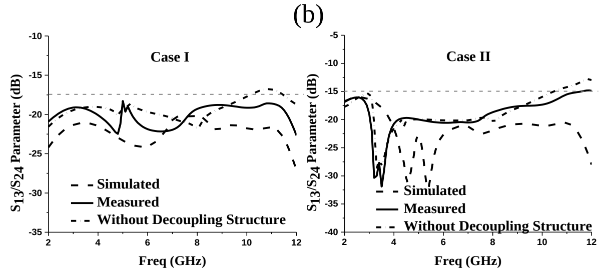
As in Fig. 1, it can be seen that Antenna 1-2 and 3-4 are placed side-by-side, Antenna 1-4 and 2-3 are diagonal and Antenna 1-3 and 2-4 are placed across each other. The effect of decoupling structure on isolation of antenna elements for both Case I and II, can be observed clearly in Fig. 7. Side-by-side isolation is represented by S_{12} / S_{34} – parameter, diagonal isolation is represented by S_{14} / S_{23} - parameter, while isolation between antenna elements placed across each other is represented by S_{13} / S_{24} – parameter. The overall isolation with isolating structure is better than 20 dB. The radiation patterns in E and H-plane of proposed antenna (Case I and Case II) are observed at 3.5 GHz and 5 GHz and are plotted in Fig. 8. The proposed antenna gives good gain results over whole UWB band except for the notched WiMAX band as depicted in Fig. 9.



(a)

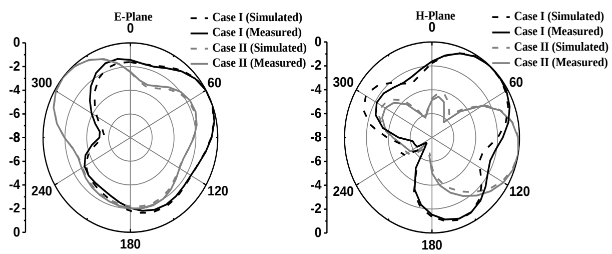


(b)

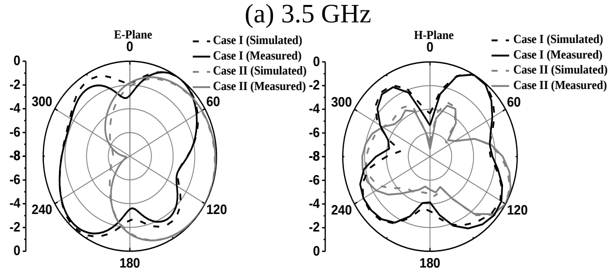


(c)

Fig. 7. Mutual Coupling with and without decoupling structure: (a) side-by-side, (b) diagonal, and (c) across.



(a) 3.5 GHz



(b) 10 GHz

Fig. 8. Normalized radiation plots: (a) 3.5 GHz and (b) 10 GHz.

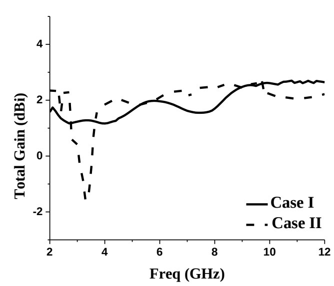


Fig. 9. Gain of proposed antenna.

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 topologies (side-by-side, diagonal and across) using equation (2):

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

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. 10 (a - f), the results are well within the allowable limits for both Cases (I and II). In Case II the CCL value at WiMAX (3.2-3.8 GHz) band is above 0.5 bits/sec/Hz, because of the anti-resonant effect of band notching structure.

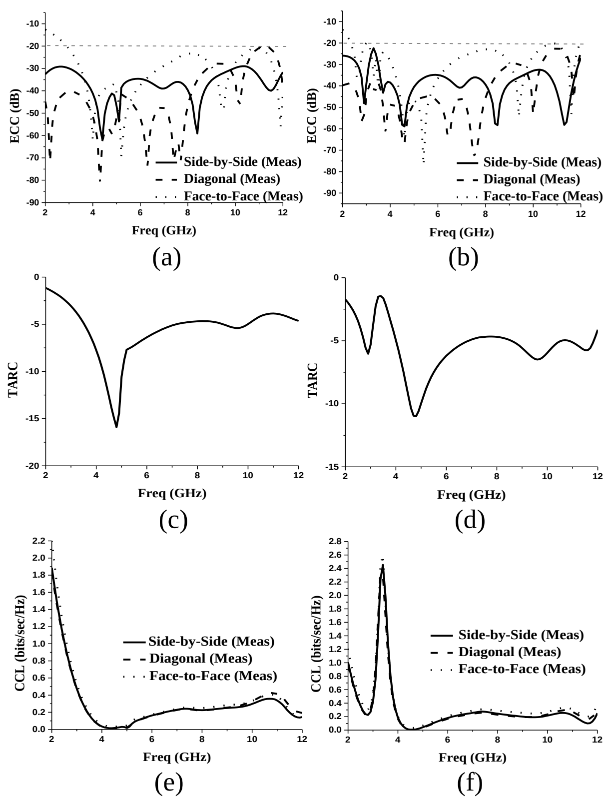


Fig. 10. MIMO/Diversity performance parameters: (a) ECC for Case I, (b) ECC for Case II, (c) TARC for Case I, (d) TARC for Case II, (e) CCL for Case I, and (f) CCL for Case II.

Table 1: Comparison of proposed MIMO antenna with existing literature

Ref.	Isolation (dB)	No. of Ports	Antenna Dimension (mm^3)	Reconfig-urability
[5]	> 20	2	50×30×1.6	No
[6]	> 20	2	18×34×1.6	No
[7]	> 20	2	23×39.8×1.524	Yes
Proposed antenna	> 20	4	26×30×0.8	Yes

The proposed MIMO antenna elements are compact as compared to various antennas reported in literature previously [5-7]. The comparison of proposed antenna characteristics with these MIMO antenna designs is listed in Table 1.

IV. CONCLUSION

A compact our port multiple-input multiple-output (MIMO) antenna with electronically reconfigurable WiMAX (3.5 GHz) band notch characteristics is proposed for ultra-wideband applications. The design exhibits good impedance match over entire UWB band. Enhanced isolation is achieved by using simple decoupling structure. 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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