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Enhanced Design of a Meta-Surface Embedded Ultra-Wideband MIMO Antenna with Frequency-Notched Features

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Abstract: An improved design of compact metasurface embedded MIMO Monopole antenna in ultra-wideband range is projected for band rejection purpose. Two alike antennas energized by two microstrips are the main part of this MIMO design. Periodic placement of square shaped metamaterial on the radiation plane improves the gain of the antenna. The gain improves significantly compared to normal antenna due to metamaterial. Notch frequency is realized by using L-shaped$\frac{\lambda}{4}$ spur line on each feed part .The intended antenna provides reflection coefficient well below -10 dB throughout the UWB range. A peak frequency notch at 5.5 GHz is considered to reject it from 5-6GHz WLAN band. Results achieved from simulation of the fabricated prototype were experimentally verified concerning impedance, gain and radiation characteristics.

Keywords: diversity gain; ECC; frequency notch; meta surface; MIMO; spur line

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1. Introduction

Since February 2002 there were considerable progress in UWB technology when FCC declared commercial usage of this UWB technology , 3.1 GHz to 10.6 GHz [1] with some power constraint. After that, UWB technology has quickly advanced, becoming a promising option for high-speed wireless communication in many applications.Interference of narrow bands like FBWA- 3.15 GHz, WLAN (5.15-8.15) GHz andX-band satellite (7.25-7.75 GHz) downlink is a big problem. There are various filtering technique introduced to avoid this interference [2-4].

Latterly, MIMO has shown immense prospective to intensify the data rate further. This strengthen the channel capacity considerably by using multiple antennas. MIMO builds a more established connection and reduced congestion.

Here a simple and new improved method for designing MIMO antenna with square shaped meta material on the same plane of radiating patch and $\frac{\lambda}{4}$ spur line on the feeding part .Few MIMO antennas were introduced in [3–6] and [10-11,13].Here novelty is, i) improvement of the gain by introducing meta surface structure ii) desired reflection coefficient and low mutual coupling and ii) simple filter for WLAN band rejection.

2. Antenna Design

Figure 1 depicts a compact MIMO antenna with meta-surface integrated frequency-notch functionality. A stub with dimension Wst x L_{st} is used for isolation. Here monopole antenna with circular shape and a fed of 50 Ohm micro strip line with dimension W_m x (L_G+t) [4] is used as the radiator .A spur line of length l_{vs} and width W_s is entrenched on the feed part of the antenna. The design parameters are given in Table 1.

Table 1. Design Parameters of the Antenna $\varepsilon_r = 2.33$, *tan* $\delta = 0.0012$ and thickness h = 0.7875 mm.

Table-1 Design Parameters of the Antenna $\varepsilon_r = 2.33$, *tan* $\delta = 0.0012$ and thickness h=0.7875 mm

L	W	L_G	R	t	w_m	w_s	W_{st}	L_{st}	l_{hs}	l_{vs}	a_i
50	100	21.5	12.5	0.5	2.5	0.32	2	15.5	0.9	9.67	2

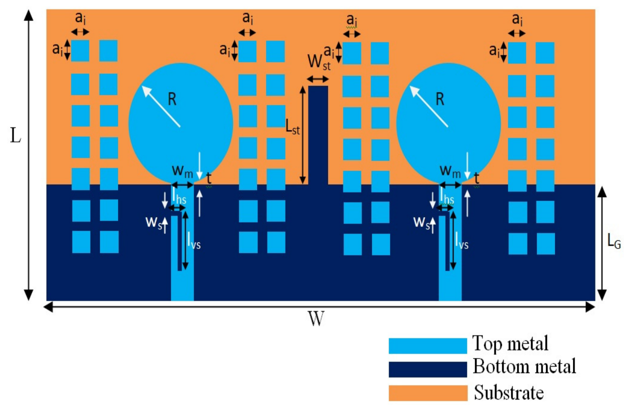

Figure 1. Schematic of a microstrip fed L-shaped spur line resonator loaded proposed Antenna.

A notch frequency f_n from a spur line with length l_{vsi} is given by established Equation [9],

$$l_{vsi} = \frac{\lambda_{ni}}{4} = \frac{c}{4 f_{ni}\sqrt{\varepsilon_{reff}}} \tag{1}$$

$$f_{ni} = \frac{c}{4\sqrt{\varepsilon_{reff}}\, l_{vsi}} \tag{2}$$

Where ε_{reff} is the effective dielectric constant. The upper and lower view of the fabricated antenna are shown in Figure 2a,b, respectively.

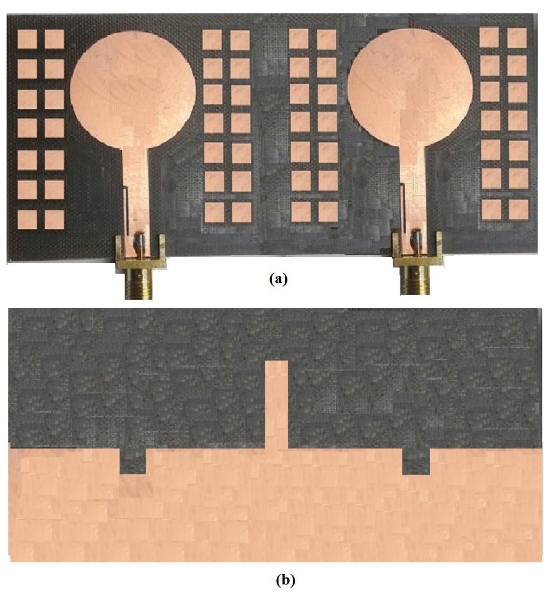

Figure 2. Fabricated structure of Metamaterial implanted Monopole antenna (**a**) upper view (**b**) lower view.

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Figure 3 shows equivalent circuit of one antenna where R_a is corresponding radiation resistance of the antenna and L_a and C_a represent inductance and capacitance. $Y_a = G_a + jB_a$ is the admittance of the monopole antenna where, G_a (real) and B_a (imaginary) admittance part .The metamaterial impedanceis $Z_{ss}=R_{ss}+jw\, L_{ss}+1/jwC_{ss}$..

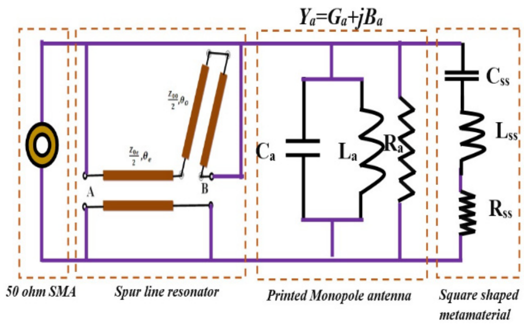

Figure 3. Equivalent circuit of the planned antenna.

Where $L_{ss}$is the inductance corresponding to the length (hi=li) of the square shaped meta-surface and Css is adjacent unit cell capacitance . Rss is the copper patch resistance.

3. Results and Discussion

The projected MIMO antenna is planned, simulated using [8] and measured within anechoic chamber. The antenna is meticulously examined for input impedance matching and radiation characteristics. Figure 4 depicts S_{11} and S_{22}variation of the planned antenna. The projected MIMO encumbered with a spur line a separate frequency notch is observed at 5.63 GHz where simulated is 5.53 GHz. Figure 5 indicates the mutual coupling coefficient $S_{21}$and S_{12} vs frequency. Basically ground stub improves the isolation between two antenna as revealed from coupling coefficient graph. Taking into consideration of satisfactory isolation and minimum perturbation of radiation pattern , the stub dimensions are chosen. From Figure 5 it is also clear that without stub very less isolation is achieved.

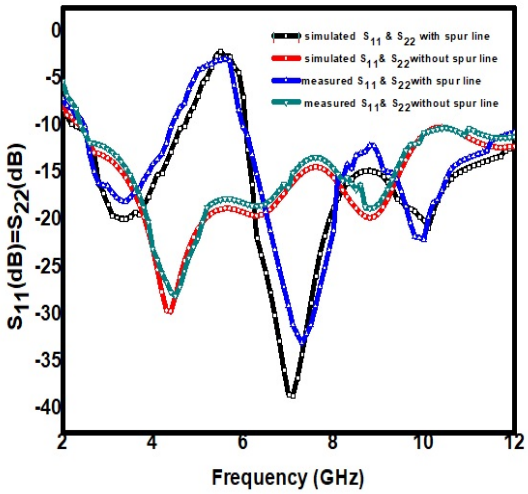

Figure 4. Return loss Vs frequency Plot.

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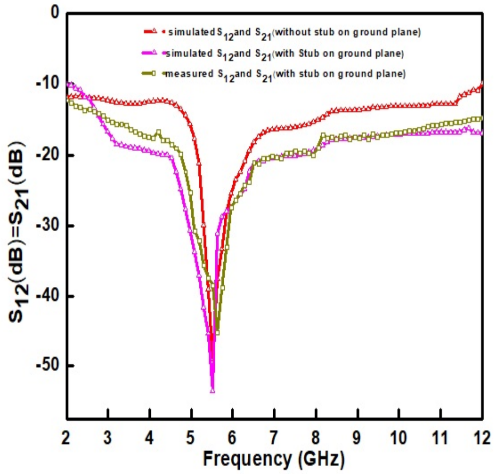

Figure 5. Mutual coupling coefficient |S21| vs Frequency plot.

Figure 6 indicates variation of measured maximum realized gain. At notch frequency 5.63 GHz the gain drops to -10 dBi while for other frequency gain ranges from 3 to 6.2 dBi which is little bit higher than normal circular monopole antenna due to periodic placement of square shaped meta material on the radiating plane of the antenna. Radiation pattern at 3.5 GHz, 6.5 GHz and 7.5 GHz are shown in Figure 7. For E-plane, a null along the axis of the monopole (y-axis) is obtained and for H-plane nearly omni-directional pattern is obtained. The frequencies falls on UWB spectrum not including the notch frequency. Also novelty is enhancement of gain due to the periodic arrangement of square-shaped metasurface structures.

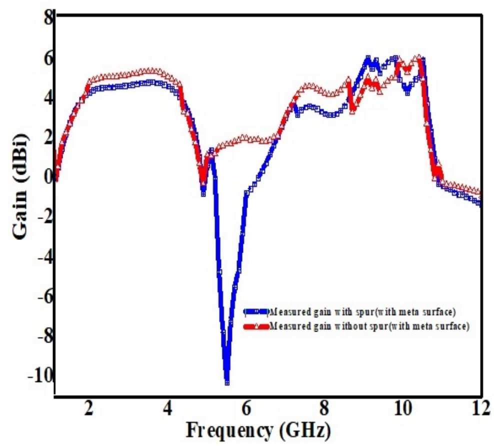

Figure 6. Gain Vs frequency plot.

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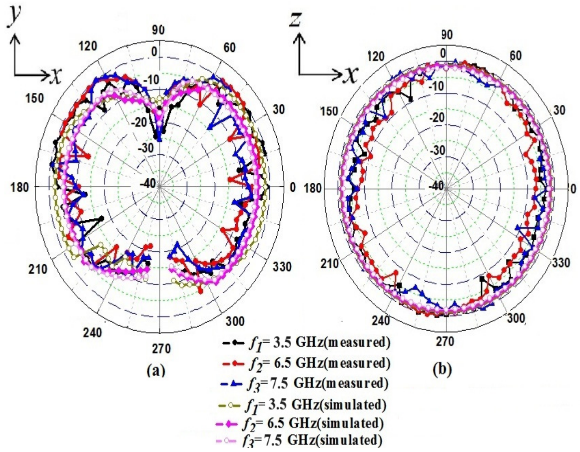

Figure 7. Normalized (**a**) E (X-Y) and (**b**) H (X-Z) co-polarization radiation pattern.

4. Diversity Analysis

This section focuses on analyzing various constraints related to dissimilar diversity concepts. In this study, parameters such as ECC, DG, MEG, and CCL are evaluated. The ECC parameter represents the correlation between the radiation patterns of multiple antennas operating simultaneously. Similarly, DG is a significant metric that provides insights into the effectiveness of diversity. The ECC, derived from S-parameters, can be computed using Equation [4], where Sii is the reflection coefficient, and Sij represents the mutual coupling between the two antenna ports. The relationship between ECC and DG is described by the following equations:

$$ECC_S = \frac{|S_{11}^{*}S_{12} + S_{21}^{*}S_{22}|^2}{\left(\left(1 - \left(|S_{11}^2| + |S_{21}^2|\right)\right)\left(1 - \left(|S_{22}^2| + |S_{12}^2|\right)\right)\right)} \quad (3)$$

$$DG = 10\sqrt{1 - (ECC)^2} \quad (4)$$

From Equation 3 and 4 ECC and DG are calculated and presented in Figures 8 and 9, respectively. The analysis demonstrates excellent diversity performance, with ECC values remaining below 0.5 and diversity gain (DG) approximately 10 dB across the entire frequency range. Table 2 presents comparison table.

Table 2. Comparison Table.

Ref.	MIMO Type (UWB/WB/CR /Notched)	Number of elements	Isolation Enhancement Techniques	IBW of the MIMO Antenna (GHz)	Isolation achieved (dB)	S_{11}(dB)	VSWR	Gain (dBi)
[4]	UWB	2	Using quasi self-complimentary concept	2.19-11.07	Better than 20 dB	-15	1.43	3.85-4.67
[5]	UWB	4	AFS miniaturizing technique	2.94–14	Better than 17 dB	-25	1.19	5
[6]	UWB	4	four-directional staircase-shaped decoupling	2.3-13.7	Better than 22 dB	-28	1.08	1.4-4.6
[10]	Dual WB	2	T-shaped stub and defected ground	24.6–42.1 and 50.1–52.5	Better than 44 dB	-25	1.19	-
[11]	UWB	2	Metal strip acting as reflector	3.1-10.6	Better than 14 dB	-15	1.43	5.2
[13]	UWB	4	Orthogonal, tapered feed	3.1-10.6	Better than 20 dB	-28	1.08	3
This Article	Notched UWB	2	I-shaped Stub on the ground plane	2-12GHz with notch band 4.8-6.0GHz Centre frequency 5.63GHz	~(20-22)dB	-28	1.08	3-6.2

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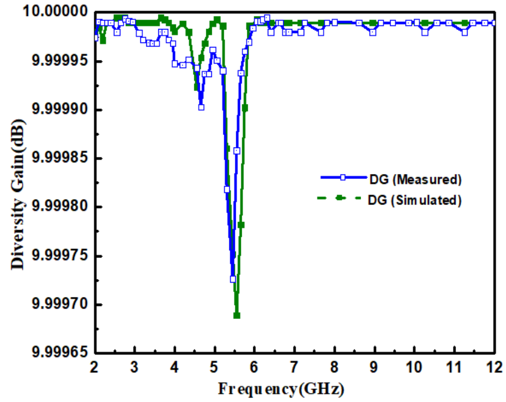

Figure 8. Diversity gain Vs Frequency plot.

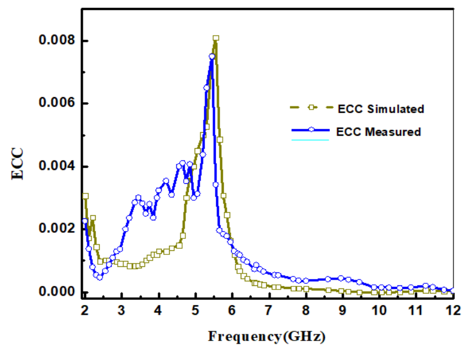

Figure 9. ECC Vs Frequency plot.

5. Conclusions

A new compact antenna design with two monopole elements and a band rejection feature for WLAN is presented. The unique feature of this design is the use of square-shaped meta-material to improve the antenna's performance. To reduce interference, a stub is placed between the two similar circular monopole antennas, which are powered by microstrip feeds. An L-shaped spur line on the microstrip feed helps block signals around 5.5 GHz. The design concept is carefully tested using advanced 3D simulation methods and accurate measurements.

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