Progress In Electromagnetics Research Letters, Vol. 101, 11–17, 2021

Spur Line Implanted Orthogonal Microstrip-Fed Ultra-Wideband MIMO Linear Taper Slot Antenna with WLAN Band Rejection

Chittajit Sarkar* and Susobhan Ray

Abstract—A compact ultra-wideband multiple-input-multiple-output (MIMO) orthogonal microstrip fed linear tapered slot antenna (LTSA) is planned for frequency notched applications. The projected MIMO antenna comprises two indistinguishable linear tapered slot antennas excited by two orthogonal microstrip feeds. In this paper, double split-ring resonators (DSRRs) are suggested to develop the isolation between two linear tapered slot antenna elements. A quarter wavelength spur line is entrenched on the feeding part of the micro-strip antenna to attain the notch frequency. The L-shaped spur line is added to the notch frequency at 5.5 GHz targeted to dodge interference from 5–6 GHz WLAN band. The planned antenna is fabricated and labelled in terms of impedance and radiation parameter measurements, compliant with that of properties achieved from full wave simulation. The antenna has congruous gain and well-built radiation pattern. Radiation pattern portrayal confirms high gain in the end-fire direction.

1. INTRODUCTION

In the areas of radar, sensing, and military communications application ultra-wideband (UWB) technology has been used for its high speed connectivity and other advantageous features for last two decades. There is a big rush of exploration of UWB technology when Federal Communications Commission (FCC) [1] permitted commercial usage for data communication within frequency band 3.1 GHz to 10.6 GHz. To reject co-occurrence of a few narrow bands, like 7.25–7.75 GHz downlink of the X-band satellite communications, IEEE 802.11 — wireless local area network (WLAN) in the frequency band of 5.15–8.15 GHz, WiMAX ranging from 3.3 to 3.7 GHz, from UWB require frequency notched UWB antenna dependent on user's requirement. Different frequency notch techniques have been proposed in [2–4]. Increasing channel capacity to a great extent, multiple antennas are embedded in the transmitter and receiver. In this context, multiple input multiple output (MIMO) technology has revealed pronounced prospective in increasing the data rate. This manuscript plans a new and simple method of scheming frequency notched 2-element UWB MIMO antenna by inserting a quarter wavelength spur line on the feed-line of the antennas. Recently, MIMO systems, which are built on a multiplexing technology agreeing several antennas at both transmitter and receiver, have materialized in UWB technology as corridor to rise channel capacity, link reliability, network coverage, and data rates. The key task in MIMO antenna scheme is to attain high isolation between multiple narrowly spaced antennas. Original perceptions of MIMO antennas have been presented for UWB schemes in the recent past [5–20]. In comparable to [7, 8], in this manuscript a satisfactory mutual isolation of -20 dB is achieved by adding five double split ring resonators (DSRRs) between two radiators. The major cause of mutual coupling is the surface wave propagation over the dielectric substrate from one antenna to another antenna. The key uniqueness of this paper is, i) improving the impedance bandwidth and attaining low mutual coupling between LTS antennas and ii) the introduction of a WLAN band

Received 11 September 2021, Accepted 22 October 2021, Scheduled 29 October 2021
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elimination by means of a simple method of stuffing an L-shaped spur line on the orthogonal microstrip fed to the antenna. This paper is systematized as follows. Section 2 describes the design of the proposed MIMO LTSA employing orthogonal microstrip feed. The microstrip line is printed on a substrate, and the tapered slot line is etched on the other plane of the substrate. This transition is accomplished by a gradual tapering of the slot line. Since the slot-line is a balanced transmission line, a wide-band balun is an important component in the antenna design. To attain a broadband transition, a microstrip open stub and a slot line short stub are used a virtual short and a virtual open at the point of transition, respectively. A balun is formed at the crossover which matches the unbalanced microstrip line to the balanced slot line of the antenna element. This electromagnetic coupling arrangement permits signal transmission from the microstrip transmission line to the slot line. The stronger the electromagnetic coupling is, the better the transition is. The frequency notching method has insignificant influence on the radiation characteristics of the antenna. The measured impedance and radiation characteristics of the fabricated antenna are discussed in Section 3. MIMO antenna scheme, diversity parameters like envelop correlation coefficient (ECC), diversity gain (DG) are discussed in Section 4. This paper concludes in Section 5.

2. ANTENNA DESIGN

Figure 1(a) shows the schematic of the planned spur line embedded frequency notched MIMO UWB antenna with two identical LTSAs separated by five DSRRs. A linear tapered slot antenna with slot width L_{s1} fed by an orthogonal microstrip line of width X_1 and length L_m acts as the basic UWB radiator. A quarter wave length spur line, which is basically an extremely narrow slot of length l_{vsi} as shown in Fig. 1(b), is accommodated on the feeding microstrip. The dimensions of proposed prototype antenna are shown in Table 1. Embedding a quarter wave spur line of length l_{vsi} yields a notch frequency

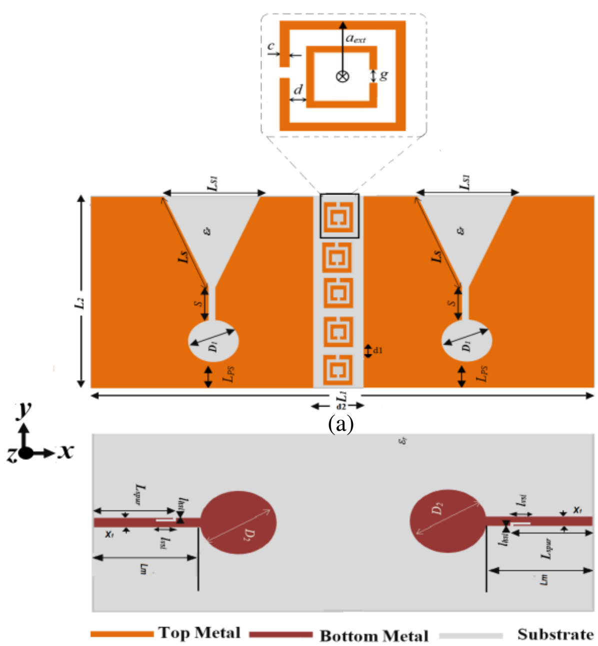

Figure 1. Schematic of an orthogonal microstrip fed MIMO Linear Tapered Slot Antenna (LTSA) loaded with spur line resonator. (a) Top view, (b) bottom view of MIMO LTSA.

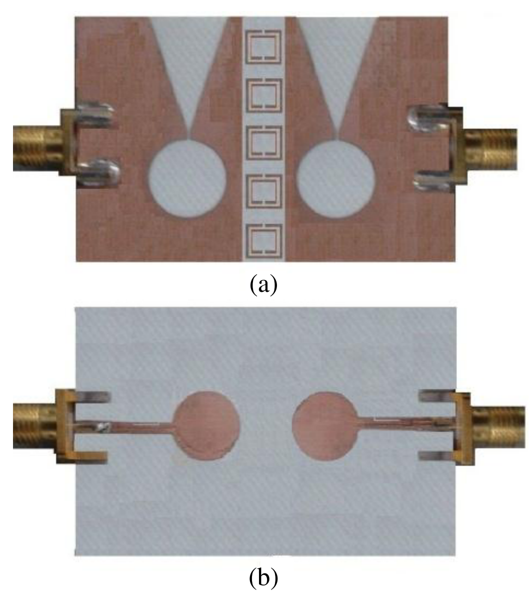

Figure 2. Fabricated structure of spur line resonator embedded orthogonal microstrip fed MIMO Linear Tapered Slot Antenna separated by five DSRR. (a) Top view, (b) bottom view.

Table 1. Design parameters of the proposed spur line loaded MIMO LTSA $\varepsilon_r = 2.33$, $\tan\delta = 0.0012$ and thickness $h = 0.7875$ mm, $d2 = 5.6$ mm.

Antenna, Spur line and DSRR parameters (in mm)								
L_1	L_2	L_S	L_{S1}	X_1	L_{PS}	L_M	D_1	D_2
80	40	16	09	1.7	8	25	11	10
s	L_{spur}	l_{hs1}	l_{vs1}	a_{ext}	c	d	g	$d1$
3	18.9	0.5	9.67	2.5	0.35	0.6	0.7	2.5

f_n given by well-known empirical equation [21],

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

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

where ε_{reff} is the effective dielectric constant. Fig. 2 shows a fabricated prototype of a single notched MIMO LTS UWB antenna. Figs. 2(a) and 2(b), respectively show the top view and bottom view of the fabricated structure of a microstrip fed MIMO linear tapered slot antenna loaded with a spur line resonator.

3. RESULTS AND DISCUSSION

The proposed antenna is simulated using an electromagnetic simulator [22] and verified for impedance and radiation characteristics using a Keysight PNA-X N5224A network analyser. The radiation pattern measurement was carried out using a broadband pre-amplifier (Agilent 83051 A) attached with a broadband horn as the transmitting antenna while the projected antenna was in receiving mode in a completely calibrated anechoic chamber. Fig. 3 shows the simulated and measured S_{11} and S_{22} values of the proposed MIMO antenna. A distinct frequency notch is observed at 5.53 GHz due to the spur line. Fig. 4 displays the simulated and measured mutual coupling coefficient S_{21} and S_{12} vs frequency.

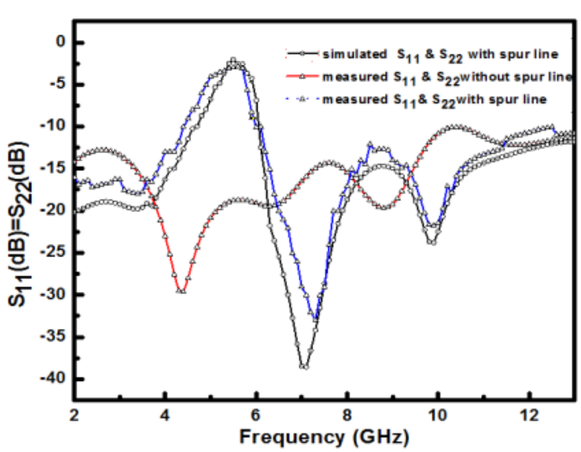

Figure 3. Simulated and measured return loss vs frequency.

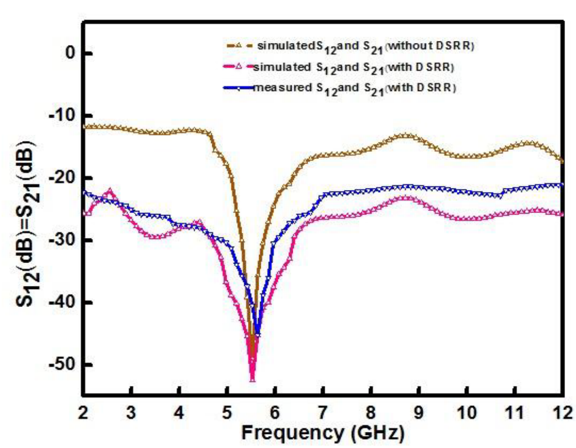

Figure 4. Simulated and measured mutual coupling coefficient $|S_{21}|$ for the MIMO LTSA with and without DSRRs.

The isolation between two LTSA ports is improved by DSRRs. The length and width of the DSRR are determined after methodical simulation to confirm adequate isolation and insignificant perturbation in the radiation pattern. The isolation between two LTSAs is significantly enhanced by placing five DSRRs in between these two similar LTS antennas. DSRR acts as an absorber, and electromagnetic waves traveling in the x-axis direction inside the DSRR are attenuated. For this reason, when the DSRR structure is applied between antennas, the degree of isolation between antenna elements has been improved.

The measured maximum realized gain with and without spur line resonator versus frequency plot of the prototype LTSA, shown in Fig. 5, clearly indicates a sharp reduction of gain to -8.9 dBi at notch frequency 5.61 GHz whereas the gain ranges from 2 to 7.8 dBi in the rest of the UWB spectrum. The simulated radiation efficiency Vs frequency is plotted in the same Fig. 5. Radiation efficiency is found above 75% over the entire UWB except at notch band. The measured normalized E (x-y) and H (y-z) plane radiation patterns are presented in Fig. 6. Figs. 6(a), (d) depict E (x-y) and H (y-z) co- and x-pole radiation patterns at 4 GHz; Figs. 6(b), (e) depict E (x-y) and H (y-z) co- and x-pole radiation patterns of 7.5 GHz; and Figs. 6(c), (f) E (x-y) and H (y-z) co- and x-pole radiation patterns of 9.5 GHz, respectively. Thus, the proposed antenna offers very low cross-polarization over its entire impedance bandwidth. The plot reveals that the antenna exhibits directional pattern in both E-plane (x-y plane) and H-plane (y-z plane). The frequencies are selected over the UWB spectrum barring the notch frequency where the spur line entrenched notch filter does not grant the antenna to radiate.

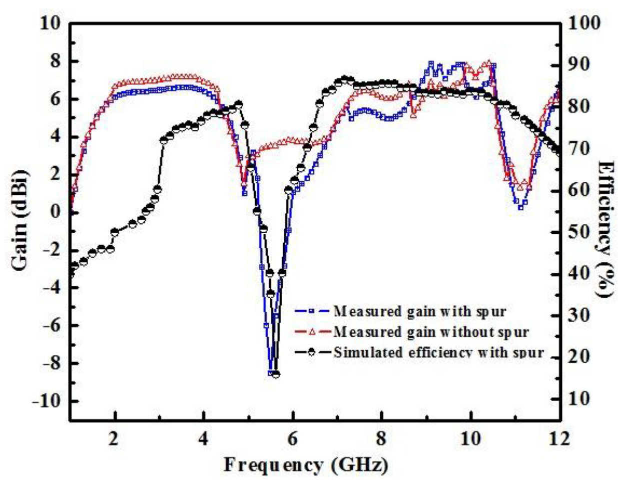

Figure 5. Measured gain and simulated efficiency characteristic of the proposed spur line loaded MIMO LTSA.

4. DIVERSITY EXPLORATION

We are very much attentive about the diversity parameters like envelop correlation coefficient (ECC), diversity gain (DG), mean effective gain (MEG), and channel capacity loss (CCL). ECC mostly describes the correlation between different channels used for communication, or it can be agreed that the value of ECC for MIMO antenna system explains correlation between the radiation patterns of different antennas simultaneously. Equally, DG is added important element which gives the information about the usefulness of the diversity. For two-element MIMO antenna configuration, the calculation of ECC (from S-parameter) can be found from the following equation [23].

S_{ii} and S_{ij} specify reflection coefficient and mutual coupling between the two antenna ports, respectively. The values of DG and ECC can be calculated by using the following equation

$$\mathrm{ECC}_S = \frac{|S_{11}^* S_{12} + S_{21}^* S_{22}|^2}{\left(\left(1-\left(|S_{11}^2|+|S_{21}^2|\right)\right)\left(1-\left(|S_{22}^2|+|S_{12}^2|\right)\right)\right)} \tag{3}$$

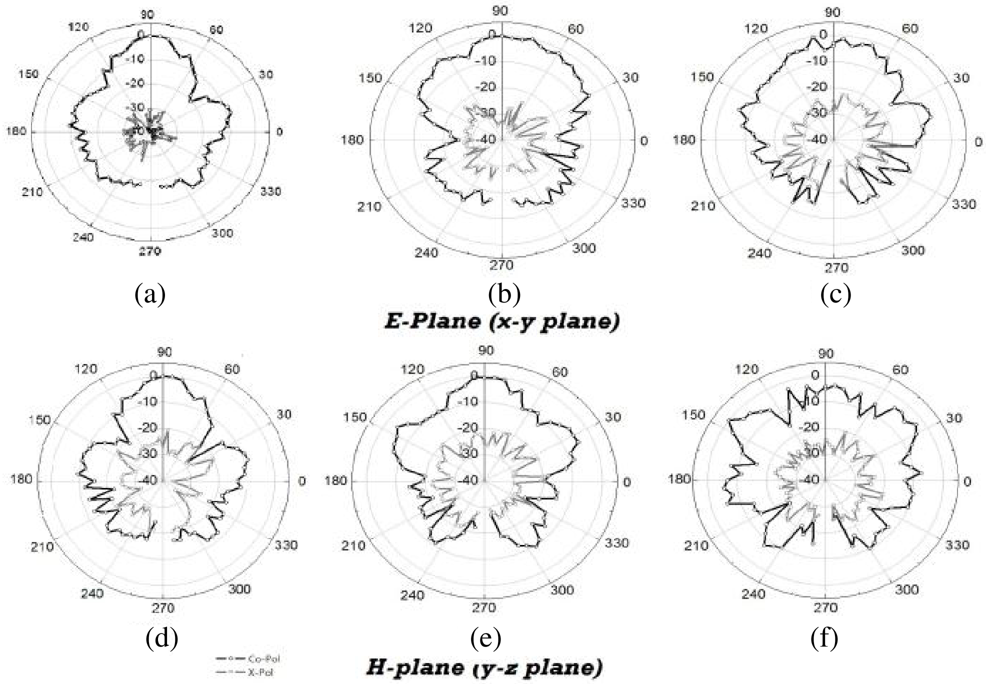

Figure 6. Measured normalized radiation pattern of LTSA. (a), (d) E (x-y) and H (y-z) co- and x-pole radiation pattern of LTSA at 4 GHz, (b), (e) E (x-y) and H (y-z) co- and x-pole radiation pattern of 7.5 GHz and (c), (f) E (x-y) and H (y-z) co- and x-pole radiation pattern of 9.5 GHz, respectively.

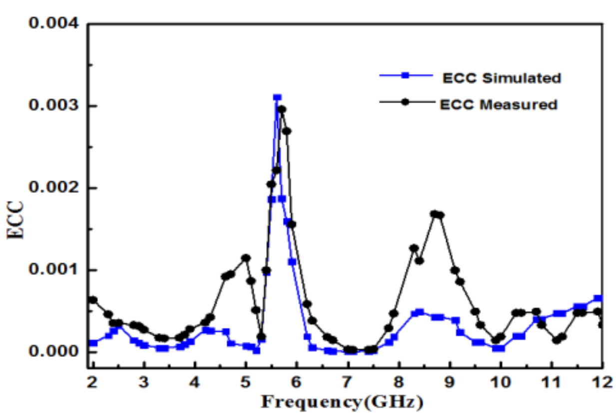

Figure 7. Simulated and measured ECC of the proposed spur line loaded UWB MIMO LTSA.

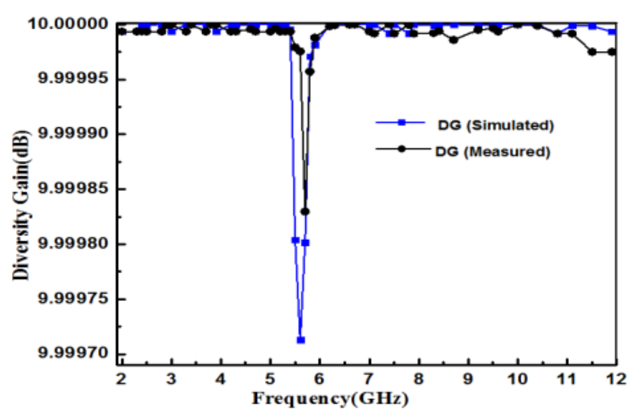

Figure 8. Simulated and measured diversity gain vs frequency plot of the proposed spur line loaded UWB MIMO LTSA.

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

The measured and simulated ECC curves using Eq. (3) and measured and simulated DG vs frequency using Eq. (4) are plotted in Fig. 7 and Fig. 8, respectively. It is observed that the value of ECC is < 0.5 while the value of DG is ~ 10 dB throughout the entire ultra-wide frequency band which approves the worthy diversity performance. These values are suggestive for agreeable diversity performance. Table 2 presents an amalgamated assessment of the proposed WLAN band UWB MIMO antenna with various other proposals.

Table 2. Summary table of various isolation improvement techniques in UWB/WB/CR/notched MIMO antenna design.

Ref.	MIMO Type (UWB/WB/ CR/Notched)	Number of elements	center-to-center distance between two antenna elements (mm)	Isolation Enhancement Techniques	IBW of the MIMO Antenna (GHz)	Isolation achieved (dB)
Liu et al. [5]	UWB	2	22	Using quasi self-complimentary concept	2.19–11.07	Better than 20 dB
Naidu et al. [8]	CR	2	33.2	Multiple EBG elements and isolation stub	Ant 1: 2–11 GHz Ant 2: 4.63–6.42 GHz	$\sim$ 25 dB over most of the IBW
Zhang et al. [9]	UWB	2	17	Wideband neutralization line	3.1–5	Better than 22 dB
Deng et al. [13]	UWB	2	18.2	Etching slots on the ground	2.4–10.6	$\sim$ (15–20) dB
Rakesh et al. [17]	Dual WB	2	22	T-shaped stub in ground plane	1.85–3.63 GHz and 5.07–7.96 GHz	17.21–22.42 dB
Rakesh et al. [18]	WB	2	16.5	U-shaped narrow metallic strip	3.04–8.11 GHz	Better than 14 dB
Rakesh et al. [19]	Dual WB	2	19.68	T-shaped stub in ground plane	2.11–4.19 GHz 4.98–6.81 GHz	Better than 21 dB
Rakesh et al. [20]	UWB	2 4	19.68	neutralization technique	3.51–9.89 GHz 3.52–10.08 GHz	Better than 21 dB
This Article	Notched UWB	2	24.6	DSRR	2–12 GHz with notch band 4.8–6.2 GHz Centre frequency 5.62 GHz	$\sim$ (20–25) dB

5. CONCLUSION

A new compact 2-element UWB MIMO LTSA with WLAN band rejection is described in this paper. It comprises two indistinguishable LTSAs excited by orthogonal microstrip feeds. Five DSRRs provide good isolation between the input ports. Two L-shaped spur lined on the microstrip feed of the LTSA are presented to generate a band rejection function around 5.5 GHz. Projected MIMO LTSA is an impending candidate for UWB applications. The planned idea is certified in an extensive manner with systematic investigation using 3-D full wave simulation and impedance and radiation features of the fabricated prototype.

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