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A TAPERED FED MIMO ANTENNA FOR IEEE INSAT BAND USING L-SLITS

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Abstract:

This paper addresses the prime challenges of UWB antennas, the proposed antenna is capable of extending its operation in to IEEE extended C-band. Using the L-silts in the antenna structure and ground plane the antenna is made to operate in MIMO mode and by simulation different s-parameter measurements are plotted. Gradual tapering of the feed is adopted taking the mathematical conclusions and much improvement is observed in the diversity of the proposed antenna. A tapered-fed compact dual band-notched MIMO/diversity slot antenna for UWB applications is proposed. Many MIMO Antennas have relatively larger size and poor isolation in comparison to the proposed design. The designed antenna has a compact size with low mutual coupling and hence provides a viable solution for many portable wireless applications .

Keywords **— UWB; C-band; MIMO;IEEE;S-Parameter; Slot Antenna.**

I. INTRODUCTION

In antenna design, the major challenge is to design an antenna that covers the whole band approved by FCC in one slot with consistent performance throughout the band. Recent trends in wireless technology demand miniaturized UWB antenna so as to be compatible with portable devices. As devices in the near future are going to be more compact and the space for antenna integration is also reducing, the antennas must be positioned within the available space. But reduction in the size of antenna will affect its radiation characteristics. Another challenge in UWB antenna design is electromagnetic interference due to the coexistence of narrowband systems such as WLAN and C-band with UWB systems. The narrowband antennas are highly efficient as they are used for long range application whereas the UWB antennas are not that efficient since they are used for short range applications. Therefore, impact of interference of UWB spectrum with that narrowband is an important issue and has to be eliminated. Further, the development of UWB-MIMO antenna systems adds more challenges in antenna design. The designs of UWB-MIMO antenna system are confronted with the same design constraints as that of single antenna with additional challenges of isolation, correlation and diversity gain. Mutual coupling between antennas in space is of major concern where antennas are placed in close proximity to each other. As it not only affects the antenna efficiency but also influences the correlation. Another difficult task that exists during the design of a UWB-MIMO antenna system is the concurrent enhancement of isolation and impedance bandwidth**.**

MIMO/Diversity techniques significantly improve the reliability and transmission capacity of a system over single-antenna systems without increasing the bandwidth and power consumption [1]. The multiple antennas installation in the transmitter and/or receiver with low mutual coupling is essential for MIMO (multiple-input-multiple-output) communication systems. The size has always been the main constraint for antenna designers. The portable MIMO devices in which multiple antennas are closely packed, inevitably results in a significant mutual coupling between antenna elements that consequently deteriorates the diversity performance. Therefore, the major problem that has to be confronted while designing a MIMO antenna is high mutual coupling between antenna elements while attaining compact size. Federal Communication Commission (FCC) officially assigned an unlicensed UWB spectrum from 3.1 to 10.6 GHz [2] for future communication. Despite of various advantages of UWB systems signal fading in multipath environments is an issue. This problem is resolved by combining UWB and MIMO (multiple-input-multiple-output) techniques. Use of MIMO technology in ultra-wideband (UWB) systems is studied in [3], which showed that it provides a significant channel capacity improvement over MIMO technology used in narrowband systems such as for UMTS [4], and WLAN [5]. Various techniques have been studied [6, 7, 8, 9, 10, 11, 12] to reduce mutual coupling between the radiating elements in UWB-MIMO systems. In [6, 7, 8, 9, 10, 11, 12] MIMO antennas were studied to enhance isolation by employing various defective ground structures (DGS) or by introducing stubs and slots between the two radiating elements. In [9] asymmetric coplanar strip (ACS) fed with an I-shaped slot in the radiator and by attaching a rectangular patch on the back is studied, while in [12] a mushroom type electromagnetic band gap structure is used between two antennas to increase the isolation.

Electromagnetic interference (EMI) is another problem of MIMO devices operating in UWB band, a viable solution to this problem is to design UWB antenna with band-notched characteristics. Therefore, different techniques are reported in the literature to suppress interference such as inserting short stub [13], an arc shaped slot [14], by etching two split ring resonator slots [15] in the antenna element, etc.

A parasitic T-shaped strip is introduced between the antenna elements to reduce the mutual coupling and a pair of L-shaped slits were etched on the ground to generate a notched band [16]. In [17] two circular shaped radiating elements fed by CPWs are designed to obtain UWB characteristics. By etching, split ring resonator (SRR) and by the collaboration of the arc-shaped strips and protruded stub, notched frequencies at X-band and WLAN band are achieved. The UWB MIMO antenna in [18] employed two heptagonal monopole elements placed orthogonally and symmetrically on the substrate for good isolation between the two input ports, a slot was cut on each of the antenna elements to create a notch in the WLAN band. In [19] a simple Y-shaped defected ground structure is etched in the ground plane to suppress mutual coupling between two antennas and improve the impedance matching. Dual notched bands (WLAN and X-bands) are achieved by etching an open ended slot and a split ring resonator in the ground plane. The designed antenna offered UWB bandwidth from 2.93 GHz to 20 GHz and -22 dB isolation.

II. DESIGN METHODOLOGY

In this paper, a tapered-fed compact dual band-notched MIMO/diversity slot antenna for UWB applications is proposed. The designed antenna has a compact size of 18×34 mm^2. It consists of a polygon shaped radiator with two L-shaped slits as notched-filter structures at WLAN and IEEE INSAT/Super-Extended C-band [20]. The performance of this antenna both by simulation and experiment indicates that the proposed MIMO antenna has good impedance matching, low mutual coupling and good diversity performance, throughout the UWB band with band-notched characteristics at WLAN-band (5.09–5.8 GHz) and IEEE INSAT/Super-Extended C-band (6.3–7.27 GHz).

The geometry of the proposed MIMO antenna, as illustrates in Figure.1, has two identical radiating elements with a common ground plane. The overall dimensions of the proposed antenna are only 18×34 mm^2 = 612 mm^2or about $0.18\lambda_0 \times 0.3410\lambda_0$ where λ_0 is the free-space wavelength at the desired first resonant frequency 3.0 GHz. However, the basic need for the UWB antenna is to obtain lower cut-off frequency i.e. 3.1 GHz while maintaining the compactness of the design. Preliminary design of the antenna starts with selecting the antenna structure and their dimensions to meet the operating frequency requirements. Monopole structure is selected for a miniaturized design of UWB antenna.

TABLE I
Comparison of the proposed MIMO antenna with other reported antennas

Reference	Size (mm×mm)	S_{11} (GHz)	Isolation (dB)	Notched Band (GHz)	Gain
[6]	35×40 = 1400	3.1-10.6	-16	-	within 3.1 dBi
[10]	27×28 = 756	3-10.6	-16	-	3 dBi
[8]	32×32 = 1024	3.1-10.6	-15	-	1.7 to 4.2 dB
[7]	26×40 = 1040	3.1-10.6	-15	-	0.9 to 6.5 dBi
[11]	30×40 = 1200	3-10.6	-16	-	-
[9]	26×26 = 676	3.1-10.6	-15	-	0.85 dBi
[12]	31×20 = 620	3.8-7.8	-15	-	-
[13]	55×13.5 = 742.5	1.85-11.9	-17.2	5.15–5.85	4.96 dBi
[14]	50×50 = 100	2.76-10.75	-15	4.75–6.12	2.8 dB)
[15]	48×48 = 2304	2.5-12	-18	5.1-6.0	stable 3 dB
[16]	38.5×38.5 = 1482.25	3.08-11.8	-15	5.03-5.97	1.4 to 3.6 dBi
[17]	40×40 = 1600	3.4 -12	-15	5.1-5.8 & 7.2-7.7	3-6.7 dBi
[18]	34×49 = 1600	3.1 - 10.6	-20	5.1-5.8	1.6 dBi
[19]	30×30 = 900	3.5 - 10.6	-15	5.1-5.8 & 7.9-8.4	-
Proposed	**18×34 = 612**	**2.9-20**	**-22**	**(5.1-5.8)&(6.7-7.1)**	0 to 7 dB

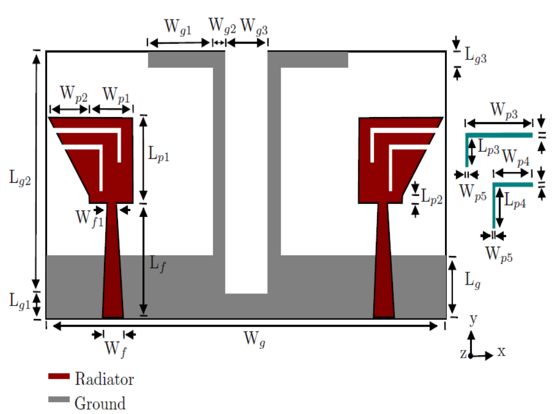


Figure.1 Geometry of the Proposed MIMO/Diversity Antenna

TABLE II
Design Parameters of the Proposed UWB MIMO/Diversity Antenna

Parameters	W_g	W_{g1}	W_{g2}	W_{g3}	L_{g1}	L_{g2}	L_g
Unit(mm)	34	6	1.35	3.8	1.25	16.75	5
Parameters	L_{g3}	W_{p1}	W_{p2}	W_{p3}	W_{p4}	W_{p5}	W_f
Unit (mm)	1	3.75	4	6.1	4.2	0.2	1.6
Parameters	L_{p1}	L_{p2}	L_{p3}	L_{p4}	L_{p5}	W_{f1}	L_f
Unit (mm)	5.5	0.35	2.75	3.25	0.25	1	6.5

and the fundamental lower resonant frequency of a proposed monopole could be approximated by the following equation [21]

$$f_r = \frac{14.4}{l_1 + l_2 + g + \frac{A_1}{2\pi\sqrt{\varepsilon_r + 1}} + \frac{A_2}{2\pi\sqrt{\varepsilon_r + 1}}}$$

where A_1 and A_2 denote the area of the ground plane and radiation patch, l_1 and l_2 denote the length of the ground plane and radiation patch, g denotes the gap between the ground plane and radiation patch, respectively, $l1$, $l2$, g, $A1$, and $A2$ all in millimeters. The proposed radiator is designed with a combination of rectangular (Lp_1 × Wp_1) and triangular (altitude 4mmand base 5.15mm) stubs to form a novel polygon shape. The polygon shaped radiator is fed with a tapered microstrip of size L_f × W_f connected at the lower edges of each radiator. Ground plane for the proposed antenna is composed of rectangular shaped and T-shaped stubs. Further, it is modified by etching a rectangular-shaped slot to form a novel inverted L-shaped ground plane to enhance the isolation between two antennas as shown in Fig.1. In Figure.2 In (Antenna A) a tapered fed line with a polygon-shaped radiator on one side and inverted L-shaped ground plane on the other side of the substrate are proposed for UWB performance. After achieving UWB performance the antenna is further modified (Antenna B) to suppress interference at WLAN band.

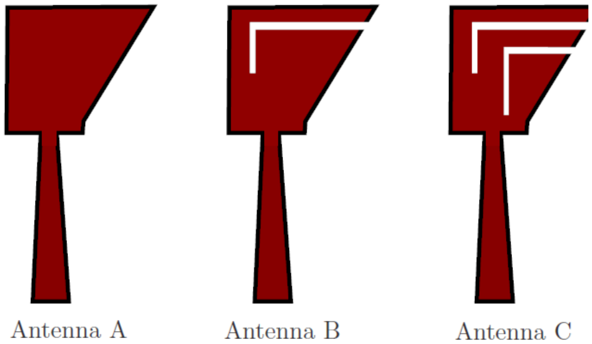


Figure.2 Different Shapes of Radiator used in the Evolution of Final Antenna A simple L-shaped slit is etched in the upper portion of the radiator to suppress the WLAN band (5.09–5.8 GHz) in UWB band. Finally to suppress the interference at higher frequencies of IEEE INSAT/Super-Extended C-band(6.3–7.27 GHz), an L-shaped slit (see Antenna C) is etched in the lower portion of the radiator as shown in Fig.2(Antenna C). The simulated S_{11} for all the geometries used in the evolution of the final design are shown in Fig.3. Furthermore, the above equation is used in design of the single element, where

$$l_1 = L_{g1} + L_{g2}$$

$$l_2 = L_{p1}$$

$$g = L_f - L_g$$

$$A_1 = 2[(L_{g2} + L_{g1} - L_g)W_{g2} + W_{g1}L_{g3}] + W_gL_g - W_{g3}(L_g - L_{g1})$$

$$A_2 = L_{p1}W_{p1} + \frac{W_{p2}(L_{p1} - L_{p2})}{2} + L_fW_f$$

As per the data given in Table II, the calculated frequency f_r is 3.4 GHz, which is almost close to the simulated result in Fig.3.1 and Fig 3.2.

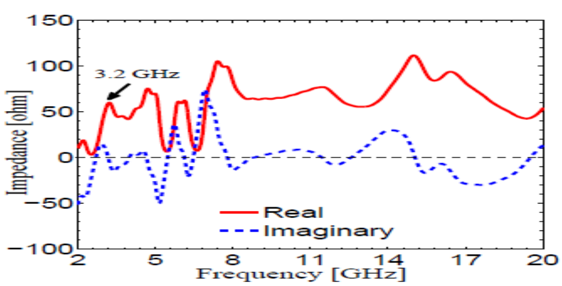


figure 3.1 simulated input impedance versus freq

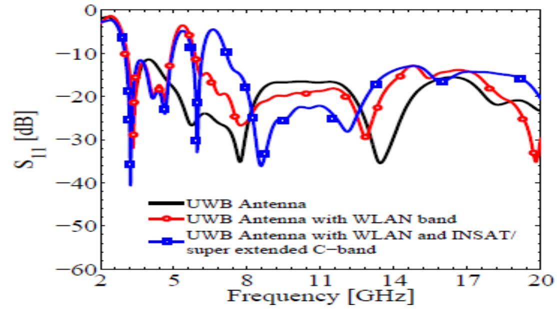


Figure3.2 Simulated S_{11} against Frequency for the Various configurations of Radiator

III.RESULTS

Current Distribution:

Fig.4 (a)-(c) illustrate the effectiveness of ground plane as a decoupling structure. It is clearly seen in Fig.(a) without L-strips that when port 1 is excited and port 2 is terminated, the coupling current exists on whole ground plane towards port 1 and port 2 as well.

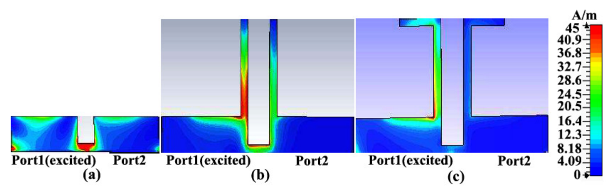


Figure 4 Current Distributions at Various Geometry of the Ground Plane

Fig (b)shows the current distribution with I-slits when port 1 is excited and port 2 is terminated, the surface current mainly occurs on ground plane towards port 1 i.e. decreases power flow from port 1 to port 2 but some portion of the current is still coupled to port 2 which in turn cause spoor isolation. Further, modification of I-strip to inverted L-strip Fig.(c)] greatly increased the isolation between port 1 and port 2 i.e S_{12} and S_{21} are more than -20 dB throughout the entire operating band.

Effect of l-slits

The dual band-notched characteristic in the proposed UWB MIMO antenna is achieved by etching two L-shaped slits in each radiator. These L-shaped slits introduce impedance mismatch between the feed line and radiating patch due to that band-notched characteristics are obtained. The upper L-shaped slit etched in the radiator provides

WLAN band (5.09–5.8GHz) with the center frequency of 5.45 GHz and the lower L-shaped slit etched in the radiator101provides (6.3–7.27 GHz) IEEE INSAT/Super-Extended C-band with the center frequency of6.6GHz. Thus, the notched band can be tuned by varying the dimensions of the L-slits.

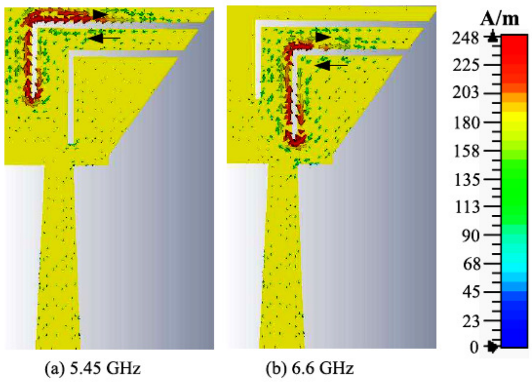


Figure 5: Current Distributions of the Proposed MIMO Antenna at (a) 5.45 GHz (b) 6.6 GHz

Further, the effect of the L-slits can also be verified by plotting the vector surface current sat (a) 5.45 GHz (b) 6.6 GHz to achieve rejection as shown in Fig.7.8. It is clearly seen inFig.7.8(a) and (b), surface current is mainly concentrated on respective L-slits such as at 5.45GHz the surface current is concentrated on upper L-slit of the radiator and at 6.6 GHz the surface current is concentrated on lower L-slit of the radiator. Here the vector currents along the slit are in opposite direction on top and bottom sides for both the cases. Hence radiation from one side current will be cancelled by the other side current. Therefore, no radiation occurs, and return loss is poor. These current distribution shows that the proposed antenna can effectively provide band-notched at WLAN and IEEE INSAT/Super-Extended C bands.

WLAN Band

The upper L-shaped slit etched in the radiator is responsible for WLAN band. For the band notched design, this slit acts as a half-guided-wavelength resonator, the length of L-shaped slit can be calculated as:

$$L_{n1} = 2(L_{p3}+L_{p5}+W_{p3}+W_{p5})$$

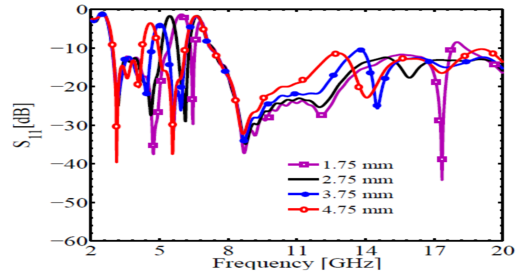


Figure 6.Simulated S-parameters against Frequency for the Various values of Lp3

Other parameters are kept constant as in Table II. It is observed that as the value of Lp3 increases from 1.75 to4.75 mm, the center of notched frequency band shifts from 5.98 to 4.59 GHz. The resonant frequency f_{n1} may be empirically approximated by:

$$f_{n1} = \frac{c}{2L_{n1}\sqrt{f\varepsilon_{reff}}}$$

Where $\varepsilon_{reff}$is the effective dielectric constant, and c is the speed of light. Here the effectivedielectric constant can be approximated to half of the dielectric constant of the FR4 material, due to the lack of ground plane. Therefore, the effective dielectric constant is 2.2. Thus, for the WLAN band, the calculated length L_{n1} is 18.6 mm. The design equation is also verified by calculating the WLAN resonance frequency for the values given in Fig.6 In Table III,WLAN frequency for different values of L_{p3} of the upper L- strip is compared with the design equation values.

TABLE III Comparison of Design Equation and Full-wave Simulation for Various values of L_{p3}

L_{p3} (mm)	L_{n1} (mm)	Resonant frequency (GHz)	
		Design equation	Full-wave simulation
1.75	16.6	6.09	5.98
2.75	18.6	5.43	5.45
3.75	20.6	4.90	5.03
4.75	22.6	4.47	4.59

IEEE INSAT/Super-Extended C-Band

The band-notched characteristics centered at 6.6 GHz of the antenna is produced by lower L-shaped slit etched in the radiator. Fig.7 shows the simulated S parameters for different values of L_{p4} with the other parameters being the values listed in Table III. It can be seen that when the L-strip length increases from 0.75 to 4.5 mm, the centered notched frequency decreases from 9.16 to 5.26 GHz. The length of lower L-shaped slit can be calculated as:

$$L_{n1} = 2(L_{p4}+L_{p5}+W_{p4}+W_{p5})$$

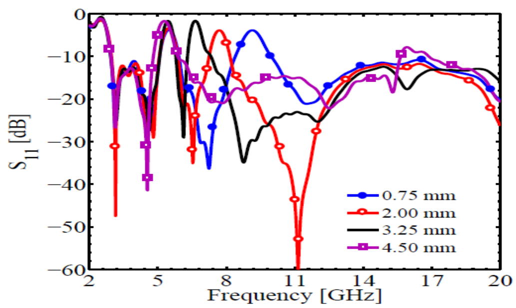


Figure 7 Simulated S-parameters against Frequency for the Various values of Lp4

The centre of the rejected frequencies are empirically approximated by:

$$f_{n2} = \frac{c}{2L_{n2}\sqrt{f\varepsilon_{reff}}}$$

Where ε_{reff} is the effective dielectric constant, and c is the speed of light in free space. For notch band the length of L-shaped slit is 15.8 mm. The length of L-shaped slit is optimized to achieve the band notch characteristic at IEEE INSAT/Super-Extended C-band. The design equation is also verified by calculating the resonance at 6.6 GHz frequency for the values given in Fig.7. In Table IV frequency for different values of L_{p4} of the lower L-slit is compared with the design equation values.

TABLE IV Comparison of Design Equation and Full-wave Simulation for Various values of Lp4

L_{p4} (mm)	L_{n2} (mm)	Resonant frequency (GHz)	
		Design equation	Full-wave simulation
0.75	10.8	9.36	9.16
2.00	13.3	7.60	7.69
3.25	15.8	6.40	6.60
4.50	18.3	5.52	5.26

S-parameters

Agilent N5230A vector network analyzer was used to validate the simulated results obtained for the proposed MIMO antenna. It is observed from the Fig.8 that the measured and simulated S11 and S21 are identical to the S22 and S12, respectively. The proposed antenna offers an impedance bandwidth of 17.07 GHz from (2.93 to 20 GHz) with isolation between two antenna elements better than -22 dB for the entire operating band. The proposed antenna shows dual-band notch characteristics to suppress interference at WLAN-band (5.09-5.8 GHz)and IEEE INSAT/Super-Extended C-band (6.3-7.27 GHz).The center frequency for WLAN and C-band has a value of S11= -1.5 dB which is high enough to show effective suppression. The measured results are in good agreement with simulated results.

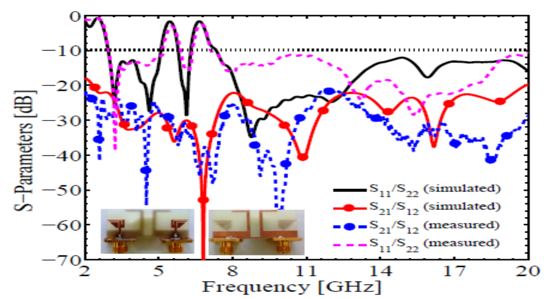


Figure 8 Simulated and Measured S-parameters Results for the UWB MIMO-Diversity Antenna

Figure 9 shows the 2-D radiation patterns at (a) 3.0 GHz (b) 5.45 GHz (c) 6.6 GHz (d)10 GHz (e) 16 GHz and (f) 20 GHz for the proposed MIMO antenna, in the xz-, yz- and the xy- planes. The proposed antenna shows nearly omni-directional radiation pattern over the desire operating band and the gain of the antenna is reduced at the band-notched frequencies. Furthermore, Fig.9 shows that the radiation patterns deteriorate at the higher frequencies due to the splitting of the radiation lobes.

MIMO performance

The MIMO behavior of the proposed antenna is evaluated in terms of envelope correlation coefficient (ECC), diversity gain (DG), mean effective gain (MEG) and total active reflection coefficient (TARC). The mutual coupling between the adjacent antenna elements and the amount of correlation between each antenna element can be studied in terms of envelope correlation coefficient the ECC can be calculated using S-parameters

$$ECC = \frac{|S_{11}^{*}S_{12} + S_{21}^{*}S_{22}|^2}{(1-|S_{11}|^2-|S_{21}|^2)(1-|S_{22}|^2-|S_{12}|^2)}$$

The ECC should ideally be zero for an uncorrelated diversity antenna but its practical limit is < 0.5. Figure 10 shows the simulated and measured ECC curves for the proposed antenna. The ECC of the proposed UWB MIMO/diversity antenna calculated using S-parameter is < 0.01. The diversity gain (DG) of the proposed UWB MIMO antenna can be calculated using $DG = 10\,(1\text{-}\,ECC^2)^{1/2}$

It is observed that ECC and DG using S-parameters is < 0.01 and > 9.95 dB, respectively as shown in Figure 10

Figure 11 shows, the radiation efficiency, multiplexing efficiency and realized gain of the MIMO antenna. The multiplexing efficiency defines as the difference in the power required for a MIMO (Antenna Under Test) to obtain a given capacity in comparative to ideal reference MIMO antenna.

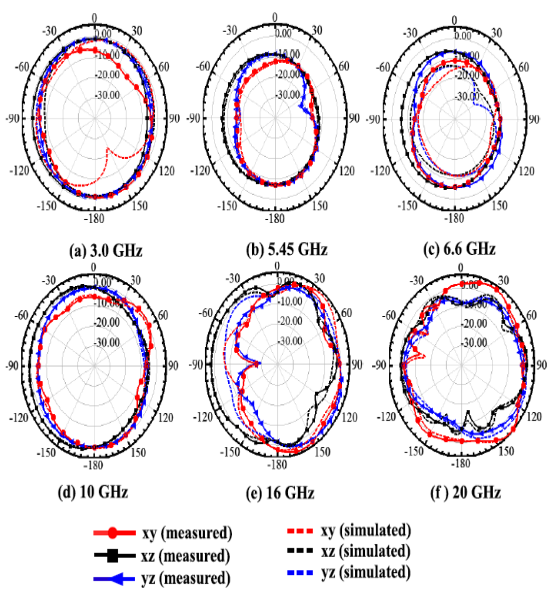


Figure 9 Radiation Pattern for the Proposed MIMO Antenna at (a) 3.0 GHz (b) 5.45 GHz (c) 6.6GHz (d) 10 GHz (e) 16 GHz and (f) 20 GHz

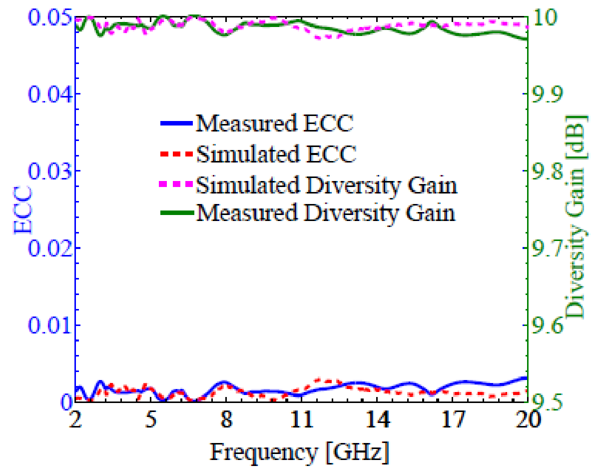


Figure 10 Measured and Simulated ECC and Diversity Gain

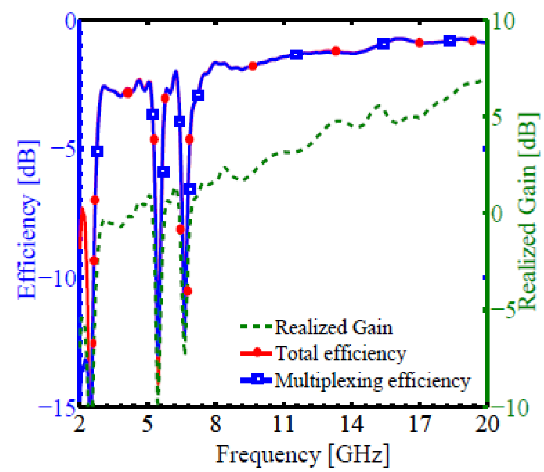
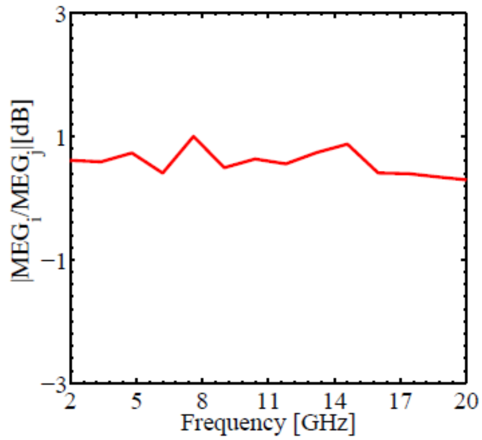


Figure 11 Efficiency and Realized Gain for the Proposed MIMO Antenna

For uniform 3D-angular power spectrum and high signal-to-noise ratio(SNR), $\eta_{MUX}$is given by [22]

$$\eta_{MUX} = \sqrt{(1-|\rho_c|^2)\eta_1\eta_2}$$

Where ρ_c is the complex correlation coefficient between the two elements, and $ECC = |\rho_c|^2$and $\eta_i$is total efficiency of the i[th] antenna element. From Figure 11 it is evident that the multiplexing efficiency and single port total efficiencies are almost identical. In order to optimize the channel capacity multiplexing efficiency is said to be a expedient parameter which not only account for the total antenna efficiency, but also for correlation and efficiency imbalance. At 5.45 GHz and 6.6 GHz there is a substantial drop in antenna efficiency and this deep drop in efficiency enables the antenna to work in high interference surroundings. The overall gain over the operating band ranges from 0 to 7 dB, at notch bands the gain drops to-10 dB (5.45 GHz) and -8 dB (6.6 GHz) respectively.



IV CONCLUSION

A tapered-fed compact MIMO antenna with dual-band notched characteristics is proposed. The designed antenna achieve an impedance bandwidth from 2.93-20 GHz with sharp rejection at WLAN-band (5.09-5.8 GHz) and IEEE INSAT/Super-Extended C-band (6.3-7.27 GHz)with an isolation less than -22 dB, by using a simple inverted L-shaped structure in ground plane, port isolation and bandwidth is improved. The diversity performance is also studied and entire results indicate that the MIMO antenna is a potential candidate for portable UWB applications.

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