Compact Reconfigurable Ultra Wide Band and 5G Narrow Band Vivaldi Tapered Slot Antenna

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***Abstract* — For a multiband communication system, a simple compact reconfigurable Vivaldi Tapered Slot Antenna (VTSA) is analyzed and designed in this paper. The designed antenna is aimed to switch between Ultra Wide Band (UWB) frequency band and one of the recent 5G low-frequency Narrow Band (NB:5.975 GHz – 7.125 GHz). The simulation return loss S_{11} is less than -11.36 dB and -11.2 dB for UWB (2.78 GHz-11.2GHz) and NB (5.96 GHz-7.65 GHz) cases, respectively. 7.03 dBi and 6.3 dBi peak gains are obtained for UWB and NB, respectively. In this work, Computer Simulation Technology (CST) software based on Finite Integration Technique (FIT) is used.**

Index Terms — Ultra Wide Band (UWB), Vivaldi Tapered Slot Antenna (VTSA), Hairpin Bandpass Filter (HPBF), Interdigital Bandpass Filter (IBF), 5G and CST.

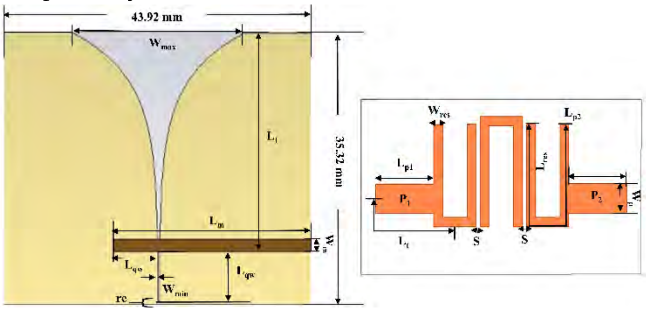
I. Introduction

The great characteristics of UWB technology help in enhancing many wireless application areas such as communication, radar, and positioning [1]. Due to the rapidly increasing number of licensed narrow-band wireless devices sharing their operating frequency bands (C-band satellite communication (3.7 GHz –4.2 GHz), WiMAX band (3.3–3.6 GHz), HIPERLAN/2 band (5.15–5.35 GHz, 5.470–5.725 GHz), and WLAN band (5.15–5.35 GHz, 5.725–5.825 GHz)) with the existing allocated UWB spectrum (3.1 GHz –10.6 GHz), a severe in-band interference (potential electromagnetic interference (EMI)) with UWB systems is occurred and this negatively impacts the performance of systems. To mitigate this interference, Bandstop Filters (BSFs) at single, dual, and multiband are integrated with UWB antenna. However, these permanent stop bands restrict the filtering antenna design in which it can't be used for another stopband according to the required applications. Also, these stop bands can't be switched off in case of no interference. Therefore, reconfigurable and frequency-agile technologies are used to overcome this drawback [2]. Furthermore, this technique helps in reducing the circuit area of the multi-band communication system such as in cognitive radio networks [3, 4]. In this paper, the antenna is designed to be switched between UWB and 5G low-frequency band (5.975 GHz–7.125 GHz) GHz used for unlicensed operations [5]. The compact UWB Vivaldi Tapered Slot antenna (VTSA) and Hairpin Bandpass Filter (HPBF) designed in [6] and [7], respectively are integrated here to design the required reconfigurable antenna. A p-i-n diode (D) MA-COM MA4AGBL912 is used for switching purpose in this paper. In this study, Rogers RO4003C substrate material with ε_r= 3.55 and h = 0.813 mm is chosen.

II. Analysis and Design of Reconfigurable UWB and NB Antenna

The required UWB antenna and filter in this paper are based on UWB VTSA and 6.55 GHz HPBF designed in [6] and, [7], respectively. The chosen antenna considered compact as compared to other VTSA used in the literature. Furthermore, in its simple design, it provides a high gain of 7.63 dBi without adding any corrugations or grating elements. The final layouts of these devices are shown in Fig1. Table 1 demonstrates the calculated and optimized parameters for the antenna, where L_T, L_{qw},W_{max},W_{min}, L_m, W_m, r, and re are the taper slot length, quarter-wave slot length, maximum aperture width, minimum aperture width, microstrip feed line length, microstrip feed line width, taper rate and the remaining distance of the non-slotted copper in the X-axis. Table 2 shows the filter's calculated and optimized parameters, where L_{res} , W_{res}, S, L_t, L_{p1}, L_{p2}, and W_p are the length of the resonator, width of the resonator, the space between two adjacent resonators, tapping length,

length of the first and second port and width of the ports, respectively.



(a) (b)

Fig.1. Layout of (a) UWB VTSA proposed in [6] and (b) 6.55 GHz HPBF proposed in [7].

TABLE 1: CALCULATED AND OPTIMIZED PARAMETERS OF THE PROPOSED UWB VTSA IN [6]

Parameters	Calculated	Optimized
L_T (mm)	27	28.3
L_{qw} (mm)	6.75	6.52
W_{max} (mm)	24.45	24.57
W_{min} (mm)	-	0.2
r	-	0.17
re (mm)	-	0.2
L_m (mm)	-	28.48
W_m (mm)	1.819	1.5

TABLE 2. CALCULATED AND OPTIMIZED PARAMETERS OF THE PROPOSED 6.55 GHZ HPBF IN [7].

Parameters	Calculated	Optimized
L_{res} (mm)	14.325	15.524
W_{res} (mm)	0.5	0.6
S (mm)	0.65	0.3
L_t (mm)	1.267	2.9
L_{p1}= L_{p2}(mm)	-	4
W_p (mm)	1.819	1.819

In this work, using all the optimized parameters shown in Tables 1 and 2, the 6.55 GHz filter is integrated into the VTSA as shown in Fig. 2. The DC biasing circuits are included in the simulation where $L_1 = L_2 = L_3 = 30$ nH, $C_1 = C_2 = C_3 = 22$ pF. For more optimization, further studies are carried out on W_{min}, separation between the filter and antenna feedlines S_p and the width of the feed line W_f (W_p=W_m) as

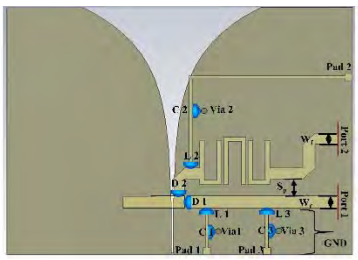
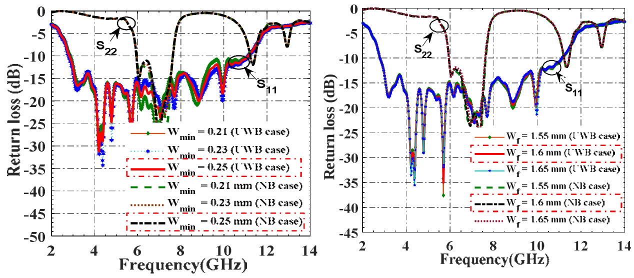


Fig.2. Layout of the proposed reconfigurable antenna.

shown in Fig .3. Narrow Band case (NB: 5.975 GHz-7.125 GHz) is obtained when D_1 is OFF and D_2 is ON and UWB case is obtained when D_1 is ON and D_2 is OFF. The chosen optimized values are highlighted with solid red color and dash-dot black color for UWB and NB cases, respectively.



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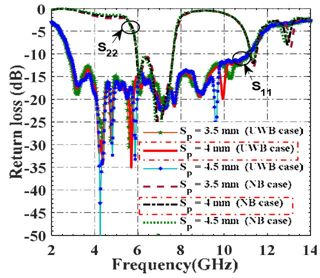


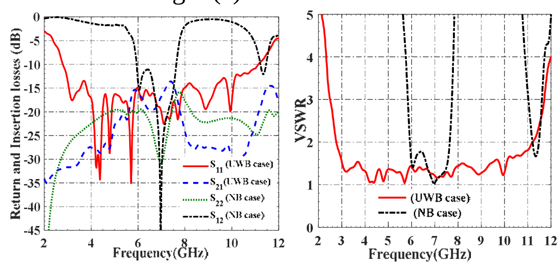
(c)

Fig.3. Parametric study of the proposed reconfigurable antenna on (a) W_{min},(b) S_p, and (c) W_f.

III. RESULT AND DISCUSSION

A. Reflection and Transmission Coefficients, VSWR and input impedance

According to the optimized values in Section II, the proposed antenna is designed and the simulated results are good in terms of matching and isolation for both cases as illustrated in Fig. 4. Figure 4(a) shows that the resulted S_{11} better than -11.36 dB and -11.2 dB for UWB (2.78 GHz-11.2 GHz) and NB (5.96 GHz-7.65 GHz), respectively. In addition to the good isolation between ports 1 and 2. The VSWR is better than 1.82 and 1.76 for UWB and NB cases, respectively as shown in Fig. 4(b). As proof of matching of the proposed antenna feeding line with 50 Ω waveguide port in CST, the real and imaginary parts of the input impedance are oscillating around 50 Ω and 0 Ω, respectively for both cases as shown in Fig. 4(c).



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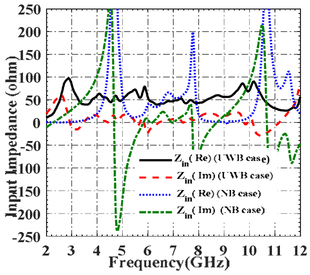

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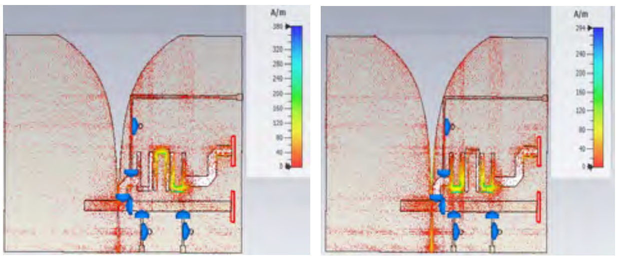
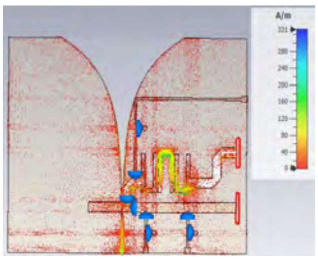
Fig.4. (a) Reflection and transmission coefficients, (b) VSWR, and (c) Input impedance of the proposed reconfigurable antenna.

B. Surface Current Distribution

To understand the mechanism of near filed radiation, the surface current distribution is displayed in Fig. 5 and Fig. 6 at different frequencies for NB and UWB cases, respectively. As it is clear for NB case, the distribution is mainly concentrated at the filter and part of the antenna transition. While it is concentrated on the antenna main feed line and the transition for UWB case with some leakage to the filter especially at frequencies near to NB (5.975 GH – 7.125 GHz) due to the coupling between them.

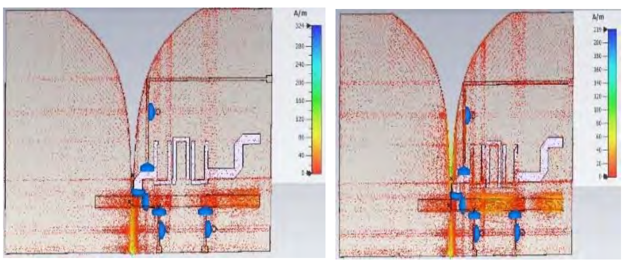


(a) (b)

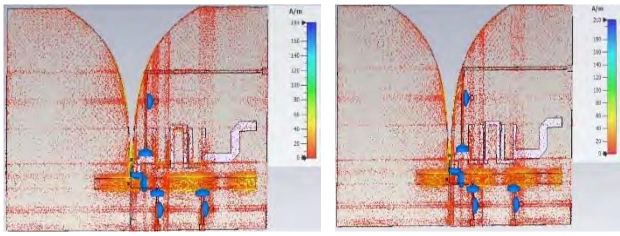


(c)

Fig.5. Surface current distribution for NB case at (a) 5.95 GHz, (b) 6.55 GHz, and (c) 7.15 GHz.



(a) (b)



(c) (d)

Fig.6. Surface current distribution for UWB case at (a) 3.1 GHz, (b) 6.85 GHz, (c) 8GHz and (d) 10.6 GHz.

IV. C. Gain and Radiation Patterns

The simulated peak gain for both cases is shown in Fig.7. For UWB case, it is increased gradually till 7.03 dBi at 8.2 GHz, then it decreases to 3.4 dB at 10 GHz. However, for NB case, the maximum reached gain is 6.3 dBi. This indicates that the proposed antenna satisfies the maximum gain in both cases. A stable end-fire radiation pattern is achieved for the proposed antenna for both cases as illustrated in Fig. 8 and Fig. 9 at different frequencies included in both bands. Because of the losses that occur at higher frequencies, small side lobe levels are added to the pattern as shown in Fig. 9 (c) and (d) for UWB case.

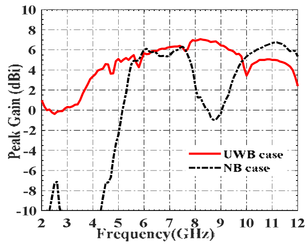
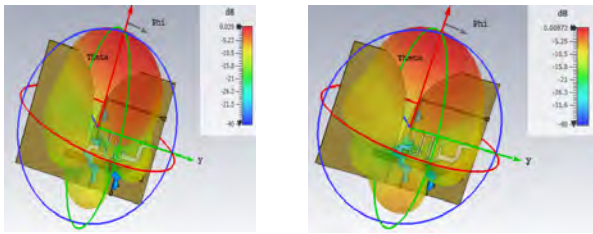
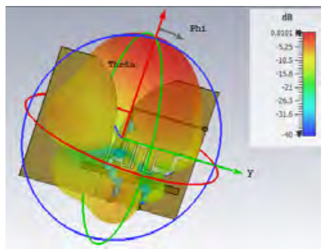


Fig. 7. Peak gain of the proposed reconfigurable antenna.

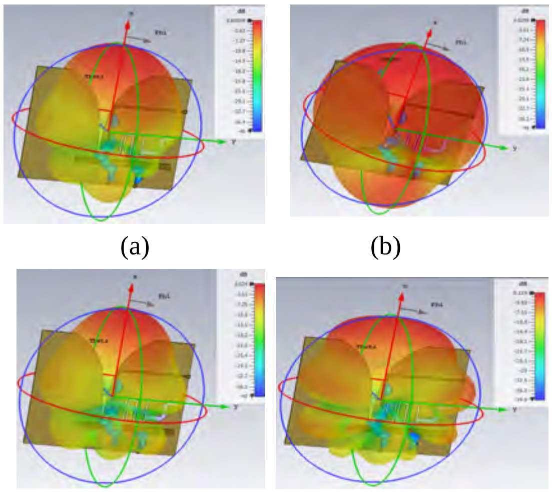


(a) (b)



(c)

Fig.8. 3D normalized radiation pattern at E plane for NB case at (a) 5.95 GHz, (b) 6.55 GHz and (c) 7.15 GHz.



(a) (b) (c) (d)

Fig.9. 3D normalized radiation pattern at E plane for UWB case at (a) 3.1 GHz, (b) 6.85 GHz, (c) 8GHz and (d) 10.6 GHz.

Finally, a comparison (Simulated results) to other related works in the literature is shown in Table 3, where the proposed antenna provides a higher gain in a smaller size.

TABLE 3. A COMPARISON TO OTHER WORKS.

Ref.	**h(mm) / ε**	**Antenna**	**Techn.**	**Switch**	**Bands (GHz)**	**Gain Max**	**Size mm^2**
This work	0.813 /3.55	VTSA	HPBF	p-i-n D	2.83-11.45 & 5.88 -7.63	7.03 dBi	43.92 x 35.32
[8]	0.4/2.2	Octave shape monopole	Slotted ground	p-i-n D	2.85–15.85, 5.01–5.79, 2.21–2.52 & 5.07–5.89, 5.05–5.90 & 2.18–2.52	5 dBi	40 x 40
[9]	1.52/4.4	Monopole	Slotted ground	Metal pads	2.5–11.7, 2.6–4.4 & 7.8–9.7	3.86 dBi	50 x 42
[10]	1/4.4	Monopole	HPBF & OLF	p-i-n D	2.8->11,.2.2–2.58.5.1–5.9	2.28 dBi	40 x 38
[11]	1.52/3.38	Bow tie	Fork res.	p-i-n D	2.3-9.3& 2.5-3, 4.3-10.3& 2.2-2.9, 3.1-4, 7.5-9.2, 9.9-11.6 & 2.2-3.1, 4.1-4.4,7.4-9.2 & 9.7-10.3	5.9 dBi	88 x 85

*OLF: Open Loop Filter, and res: resonator

V. CONCLUSION

Reconfigurable Ultra Wide Band(UWB) and 5G low-frequency Narrow Band (NB) Vivaldi Tapered Slot Antenna (VTSA) suitable for Cognitive Radio (CR) network is designed in this paper. The proposed antenna provides good matching and isolation between the two bands. Besides, stable end-fire radiation patterns are achieved in both bands at different frequencies. Although of its compact size, it provides high peak gains of 7.03 dBi and 6.3 dBi for UWB and NB, respectively.

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REFERENCES

[1] R. S. Kshetrimayum, "An introduction to UWB communication systems," *Ieee Potentials*, vol. 28, pp. 9-13, 2009.

[2] M.-C. Tang, H. Wang, T. Deng, and R. W. Ziolkowski, "Compact planar ultrawideband antennas with continuously tunable, independent band-notched filters," *IEEE Transactions on Antennas and Propagation*, vol. 64, pp. 3292-3301, 2016.

[3] H. Boudaghi, M. Azarmanesh, and M. Mehranpour, "A frequency-reconfigurable monopole antenna using switchable slotted ground structure," *IEEE Antennas and Wireless Propagation Letters*, vol. 11, pp. 655-658, 2012.

[4] Y. Tawk and C. Christodoulou, "A new reconfigurable antenna design for cognitive radio," *IEEE Antennas and wireless propagation letters*, vol. 8, pp. 1378-1381, 2009.

[5] "5G Spectrum Vision," p. 50, Feburary 2019.

[6] S. Saleh, W. Ismail, I. S. Zainal Abidin, M. H. Jamaluddin, S. A. Al-Gailani, U. U. Sheikh, *et al.*, "Simple Compact UWB Vivaldi Antenna," presented at the ICCED 2020 (6th International Conference on Computing, Engineering and Design),Accepted, Sukabumi, West Java Indonesia, October, 2020.

[7] S. Saleh, W. Ismail, I. S. Zainal Abidin, and M. H. Jamaluddin, "5G Hairpin and Interdigital Bandpass Filters," *The International Journal of Integrated Engineering*, vol. 12, pp. 71-79, 2020.

[8] R. K. Saraswat and M. Kumar, "A frequency band reconfigurable UWB antenna for high gain applications," *Progress In Electromagnetics Research*, vol. 64, pp. 29-45, 2015.

[9] D. V. Niture, S. S. Jadhav, and S. P. Mahajan, "Recon UWB antenna for cognitive radio," *Progress In Electromagnetics Research*, vol. 79, pp. 79-88, 2017.

[10] J. Deng, S. Hou, L. Zhao, and L. Guo, "A reconfigurable filtering antenna with integrated bandpass filters for UWB/WLAN applications," *IEEE Transactions on Antennas and Propagation*, vol. 66, pp. 401-404, 2018.

[11] D. S. Potti, P. Balaji, M. Gulam Nabi Alsath, K. Savarimuthu, U. Selvam, and N. Valavan, "Reconfigurable bow tie - based filtering antenna for cognitive radio applications," *International Journal of RF and Microwave Computer - Aided Engineering*, vol. 30, p. e22208, 2020.