Compact Wideband Antipodal Vivaldi Antenna for Wearable Applications

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***Abstract* — In this paper, a compact wearable antipodal Vivaldi antenna resonating at 3.5 GHz is proposed for 5G n77 and n78 bands. It is designed on a flexible polyester substrate with a dielectric constant (ε_r) of 2 and loss tangent (tan δ) of 0.005. The antenna parameters were optimized via parametric analyses using CST software with a size of 33 × 33 mm^2 (length × width). The antenna is evaluated in terms of reflection coefficient (S_{11}), gain, efficiency, radiation pattern and surface current density and its reflection coefficient is verified with measurement. This antenna attained a maximum simulated gain of 4.17 dBi and an efficiency of 98.18 % in the resonating band.**

Index Terms — Wearable technology, Antipodal Vivaldi, Sub-6, Flexible antenna, 5G, polyester.

I. INTRODUCTION

In the past few years, wearables has tremendously been applied into various fields such as biomedical, healthcare, sports, military, smart display, radar, 5G communication, WBAN, WLAN, IoT, Satellite, UHF RFID, tracking, navigation, remote computing etc. Thus, research is being conducted to design an innovative and efficient wearable antenna. Among various types of wearable antenna designs, the demand for the flexible and body-worn textile antennas are increasing. Their important features include compactness, flexibility, affordability, reconfigurability, conformality, robustness and durability. Furthermore, it must not cause any discomfort to the human skin when being worn for extended periods of time [1][2][3], besides incorporating additional design steps to ensure satisfactory operation of wireless standards and safety of the user [4]. Besides that, wrist-wearable antenna designs also need to meet the following requirements: compact, flexible substrate and radiating element, high antenna gain, wider bandwidth and cost efficient [2][5][6].

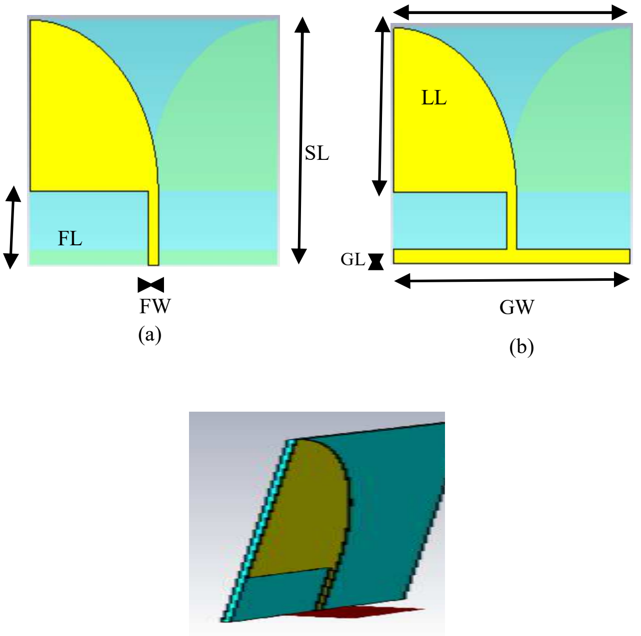
The recent release of Fifth Generation- New Radio (5G-NR) frequency bands offers promising solutions to enhance the connectivity and channel capacity since it covers multiple bands such as Global System for Mobile Communication (1.71-2.17 GHz), Personal Communication System (1.85-1.99 GHz), Universal Mobile Telecommunications System (1.92-2.17 GHz), Bluetooth (2.4-2.48 GHz), Wireless Fidelity (2.45 GHz), Worldwide Interoperability for Microwave Access (3.5 GHz) and Wireless Local Area Networks (5.4 GHz) [7]. Therefore, improving the wearable antenna designs to include operation in these bands is necessary to ensure its suitability for 5G applications [8].

Different types of dielectrics materials are available for wearable antennas such as jeans [1][9], silk [2], Teflon [10], felt [4][11][12], polyester [6][13], FR4 [7], flexible rogers [14], polyimide [3], Taconic-RF [8], and cotton [15]. Low dielectric constants fabrics are used to reduce surface wave loss and improve bandwidth [2]. Wearable structures for various applications can be found, such as patch antenna for tumor and cancer detection [2][8][9], MIMO antenna for sub 6 GHz and millimeter wave [14], patch antenna for Wi-MAX/ WLAN/Wi-Fi/5G applications [1][5][6][11]. In general, simple patch antenna designs suffer from low gain, low bandwidth, and low efficiency, which can be overcome by advert of Vivaldi antenna having advantages such as wider bandwidth, low cross polarization, high directivity, and high efficiency etc. [16][17]. In previous literatures, most of the antipodal Vivaldi antenna (AVA) designs are proposed on FR4 [16][17] [18][19][20], Rogers [17][21], and Taconic TLT [21] substrate for applications such as ultrawide band (UWB) communications [16][17], wireless communications [20], satellite [16], breast cancer detection [19], microwave and millimeter wave imaging [19][21], and Wi-MAX [22]. Nevertheless, despite being wideband and highly efficient, it is found that these AVA designs are large in dimensions, limiting their capability for wearable 5G antenna applications for compact devices.

In this paper, a compact wearable flexible AVA operating from 2.91 GHz-4.13 GHz for 5G applications is presented. Polyester fabric material is used as the antenna substrate due to its high resistance to air pollutants, toughness, and flexibility. Furthermore, it is very stable to humidity, minimal atmospheric effects of the moisture, and has a 40% resistance and resilience to deformations [13]. Besides providing wide bandwidth, the proposed antenna is capable to achieve high efficiency across the resonant frequency band. This paper is further divided into three Sections. Section-II describes about configuration and design procedure of the proposed antenna, Section-III describes the performance of various antenna parameters with the help of parametric study and measured result. Finally, Conclusion, Insights and Future Scope are described in Section-IV. This investigation was not found in previous research yet.

II. ANTENNA DESIGN AND PARAMETERS

A wearable AVA shown in Figure 1 is designed using a 100% polyester substrate with a dielectric constant of 2, a loss tangent of 0.005, and a thickness of 0.4 mm. This antenna was modelled and simulated in CST Microwave Studio software. The design of the inner and outer tappers edge of the antenna is defined in [17][20]. The total dimensions (i.e., substrate dimensions, SL × SW × ST) are 33×33×0.4 mm^3. The two fins (top and bottom radiators) are formed using copper tape with a thickness of 0.05 mm on either side of the substrate. Table 1 lists the design parameters and dimensions of the proposed antennas. A 50-Ω connector is attached to a 1.3 mm-wide feed line with good impedance matching.



(c)

Fig.1 Geometry of AVA (a) Top (b) Bottom (c) 3-D view

III. ANTENNA PERFOMANCE ANALYSIS, RESULTS AND DISCUSSION

Parametric analyses have been performed by varying the length (GL) and width (GW) of the stub connected on the bottom side separately. It is noticed that by varying the stub length from 1 to 6 mm with a step size of 1 mm, resonant frequency increases from 3.4 GHz to 3.9 GHz and by varying the stub width from 4 mm to 33 mm with a step size of 4 mm, resonant frequency increases, along with the decrease of S_{11}. Nevertheless, the bandwidth changes only slightly in both cases. Figure 2 (a) and (b) shows the comparison of S-parameters for different stub lengths and widths, respectively. A size of 2 x 33 mm is chosen as it provides the best results in terms of bandwidth, reflection co-efficient, and gain. Along with that a comparative study has been done by varying the leaf length (LL) which can be seen in Figure 2 (c). It is observed that by varying LL from 23 mm to 29 mm, resonance started moving towards lower frequency, with a simultaneous change in bandwidth and S_{11}. The final optimal size chosen for LL is 25 mm.

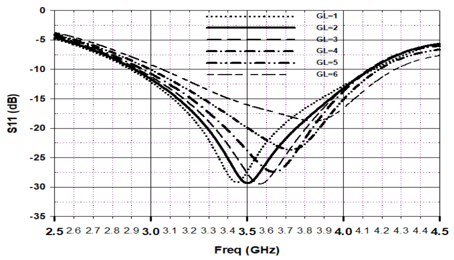
TABLE 1 Parameter values

Parameters	**Values** (in mm)
Substrate width (SW)	33
Substrate length (SL)	33
Feed width (FW)	1.3
Feed length (FL)	8
Stub length (GL)	2
Stub width (GW)	33
Substrate thickness (ST)	0.4
Copper thickness (PT)	0.05
Leaf length (LL)	25

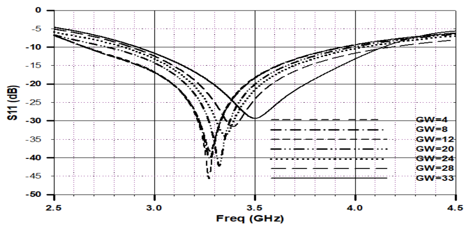
Figure 3 shows the final simulated results for the AVA, with a resonance at 3.5 GHz, S_{11} of -29.332 dB and a bandwidth of 1.224 GHz from 2.915 GHz to 4.139 GHz (34.9 % of center frequency). A gain and efficiency of 2.65 dBi and 98.18 % at resonance is also seen, respectively. However, the gain increased with frequency and attains a value of 4.17 dBi at 4.13 GHz, as seen from Figure 4 (a). Figure 4 (b) and 4(c) shows the radiation patterns for H-plane and E-plane, respectively. The H-plane pattern achieves a maximum magnitude of 2.6 dBi at 327°, with a 3 dB angular width of 261.2°. On the other hand, E-plane patterns exhibited a near-bidirectional pattern with a main lobe magnitude of 1.99 dBi at 0°, with an angular width (3 dB) of 102.6°. Figure 4(d) depicts the surface current density at 3.5 GHz. At the edges of the antenna, these currents are considerably larger compared to the other area on the radiating plane, with a maximum magnitude of 89.4 A/m. After measuring the S-parameter the resonance of the antenna shifted to 4.7 GHz instead of 3.5 GHz, as shown in Figure 3. From Figure 5 It can be seen, as the substrate and radiating element are flexible in nature, improper fabrication might lead to frequency shift. It has been verified by simulation that variations with SL, SW, GL, GW, LL and bending angle of leaf affects the resonant frequency, few of these can be seen in Figure 2 (a), (b) and (c). By combining all these analysis and mismatch of size the antenna resonance might shifted to 4.7 GHz, if proper care will be taken while fabrication, measured result can be same as simulated one. The comparison between the proposed antenna and previous literature are detailed in Table 2. The proposed AVA is good in terms of size as compared to[4][5][6][9][11][12][19], gain [6], efficiency and bandwidth with compared to all references provided in Table 2.

Table 2 Result comparison with previous work

Ref.	**Type of Antenna**	**Freq** (GHz)	**Size**	**Material** (Substrate)	**Gain**	**Efficiency (%)**	**Bandwidth** (GHz)
[11]	Patch	2.4	150×150	Felt	-	-	0.034
[1]	Humanoid	3.5	30×20	Jeans	2	-	0.3
[4]	Slot	3.5	47.2×31	Felt	6	45	0.24
[5]	Patch	5.5	180×30	Flexible	3.5	-	0.09
[6]	Patch	3.5	46×40	Polyester, Denim	0.4811, 2.679	-	0.088, 0.141
[12]	CPW Patch	2.45	72×55	Felt	-	-	0.5
[9]	Patch	2.45	45×45	Jeans	7.47	71.8	0.15
[19]	AVA	3.29, 4.24, 6.16	40×40	FR4	5.9	95	3.79
This work	AVA	3.5	33×33	Polyester	2.56	98.23	1.224



(a)



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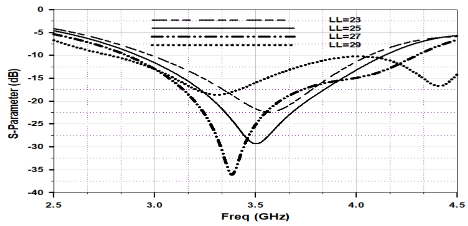

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Fig. 2 Simulated S11 by varying (a) GL (b) GW (c) LL

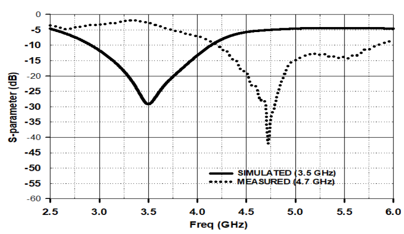
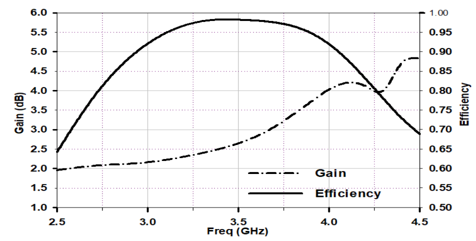
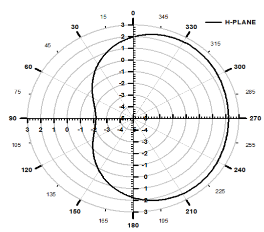


Fig. 3 Simulated S11 for ε_r=2, Measured S11, Simulated S11 for ε_r=1.34



(a)



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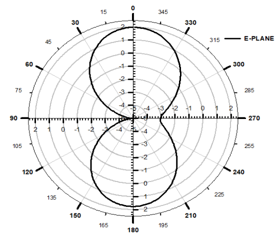

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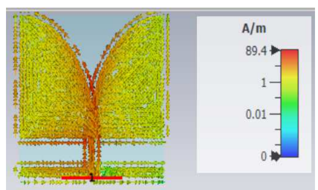
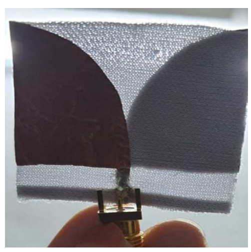
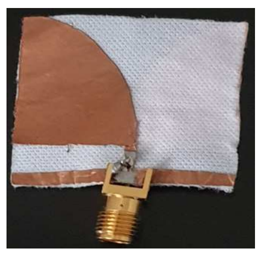


(d)

Fig. 4 Simulated (a) gain and efficiency (b) H-plane (c) E-plane radiation pattern (d) Surface current density



(a)



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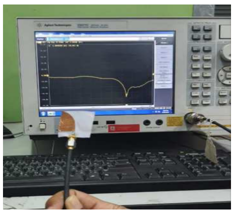

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Fig. 5 (a) Front (b) Back side of fabricated antenna and the (c) measurement set up.

IV. CONCLUSION

In this paper, a wearable antipodal Vivaldi antenna is proposed for 5G applications. The proposed antenna is made using a polyester fabric substrate with a low dielectric value and operates at 3.5 GHz, S_{11}< -10 dB with bandwidth of 34.9% (1.224 GHz). At 3.5 GHz, the antenna provides a bi-directional far-field pattern, good impedance matching, and simulated gains of 2.64 dBi and efficiency of 98.18 %. These indicates the antenna's suitability for wearable applications in the 5G n77 and n78 bands.

ACKNOWLEDGEMENT

The authors would like to acknowledge the support from University-Private Matching Fund (UniPRIMA) under grants number of 9001-0064/9002-00125 and 9001-00645/9002-00126 from Universiti Malaysia Perlis and Jabil Circuits Sdn. Bhd.

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