Single Element for the Application for a Specified 5G Frequency Range

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ABSTRACT: *This work witnesses a uniplanar bow-tie slot dipole for coplanar waveguide. We have designed the single element for the application for a specified 5G frequency range. To develop the impedance of the antenna with wide range, we have developed the bow tie slot dipole. While preparing testing, we have found that the structure offers benefits of wide impedance bandwidth with small size, low profile, and easy and cost-effective fabrication. We also found that the for series fed array bands, this antenna structure is useful.*

Keywords: Coplanar Waveguide, Bow-tie Slot Antenna, Broadband Applications

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1. Introduction

The interest for the coplanar waveguide CPW (coplanar waveguide) - fed antennas has increased s in recent years [1-4]. Accordingly, many antenna elements suitable for a CPW-fed configuration have been proposed to meet the necessary requirements of future 5G technologies defined as great capacities broadband service and transmission speeds. CPW-fed antennas are preferable for 5G mobile communication applications considering their low cost, light weight, small size, and ease of fabrication.

In order to set a strong foundation for the rapid advancement of the next-generation 5G networks, the International Telecommunication Union (ITU) announced the following spectrum for 5G, which includes the 24.25 - 27.5 GHz, 37 40.5 GHz, 66 76 GHz bands. Also, in the United States, the Federal Communications Commission (FCC) has announced the spectrum of approximately 11 GHz above 24 GHz for flexible, mobile and fixed wireless broadband, comprising 7 GHz of unlicensed spectrum from 64 to 71 GHz and 3.85 GHz of licensed spectrum in three bands: 27.5 to 28.35 GHz, 37 to 38.6 GHz and 38.6 to 40 GHz [5].

In the interest of meeting the requirements of wide-band applications in 5G frequency range 24.25-27.5 GHz [6,7], where high-gain and unidirectional radiation are crucial specification, this paper has investigated the CPW-fed dipoles with slots of bow-tie shape. The parameters of bow-tie slot are investigated to achieve both the desired operating frequency and impedance.

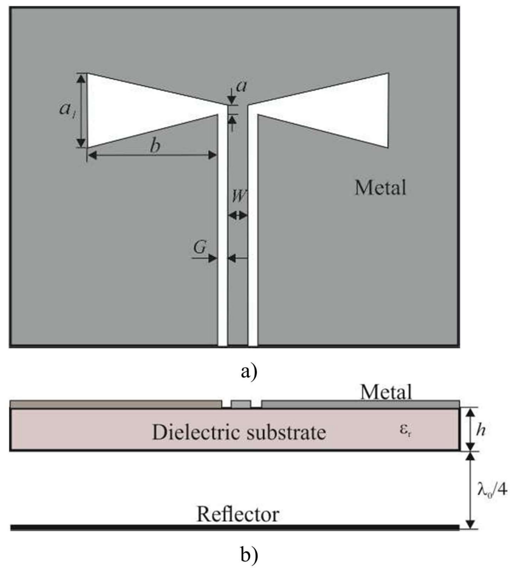

Figure 1. CPW-fed bow-tie slot dipole: a) Top view b) Side view

2. CPW-FED Bow-tie Slot Dipole

Proposed CPW-fed bow-tie slot dipole is depicted in Figure 1. The radiating element and CPW feeding line are positioned as a uniplanar structure on the same side of the substrate with thickness of h = 0.508 mm and relative permittivity of ε_r=2.54. The overall size of the substrate is λ_g x λ_g, where λ_g =9.72 mm is CPW line wavelength at the frequency f = 25.875 GHz. The bow-tie dipole has length b along which its width increases from a to a1. The widths of the strip and gap (W and G) of the CPW feeding mm and 0.3 mm, respectively [8]. The dipole is with planar reflector plate [4] at the distance $\lambda_0/4$, where λ_0=11.6 = 11.6 mm is wavelength in air for the centre frequency of the band f = 25.875 GHz.

The antenna is designed in WIPL-D software [9]. The parameters of bow-tie slot dipole are investigated to achieve a wide band coverage of the antenna.

3. Simulation Results

First analysis was conducted to determine the advantages of bow-tie slot dipole over standard rectangular slot dipole [3]. Therefore, the initial antenna design is rectangular slot dipole with equal parameters a and a_1 ($a = a_1$ = 0.3 mm). The further investigation examines impedance modification for bow-tie slot whose parameter a is constant (a = 0.3 mm) when parameter a1 rises from 0.5 mm to 1.5 mm with step 0.2 mm. Simulated results are presented in Figure 2-5 and Table 1.

Figure 2 shows dipole's impedance versus frequency for different values of parameter a_1. It is obvious that proposed dipole has two resonances: the first resonance with high impedance and the second one or antiresonance with low impedance value.

It can be seen that slot impedance at the resonance varies 12.05% when parameter al changes from 0.3-1.5 mm, while at the second resonance the impedance has greater difference from 17Ω to 27Ω which makes a relative change of 45%. Considering resonance frequency in figure 3, it decreases for 8.2% when slot width al rises from 0.3 mm to 1.5 mm, while at the same time the antiresonant frequency slightly increases from 25.88 GHz to 26.4 GHz (2%) as can be seen in Figure 4.

Since the slot impedance is very large at the resonance, it is not suitable for series-fed array of slot dipoles to work around the

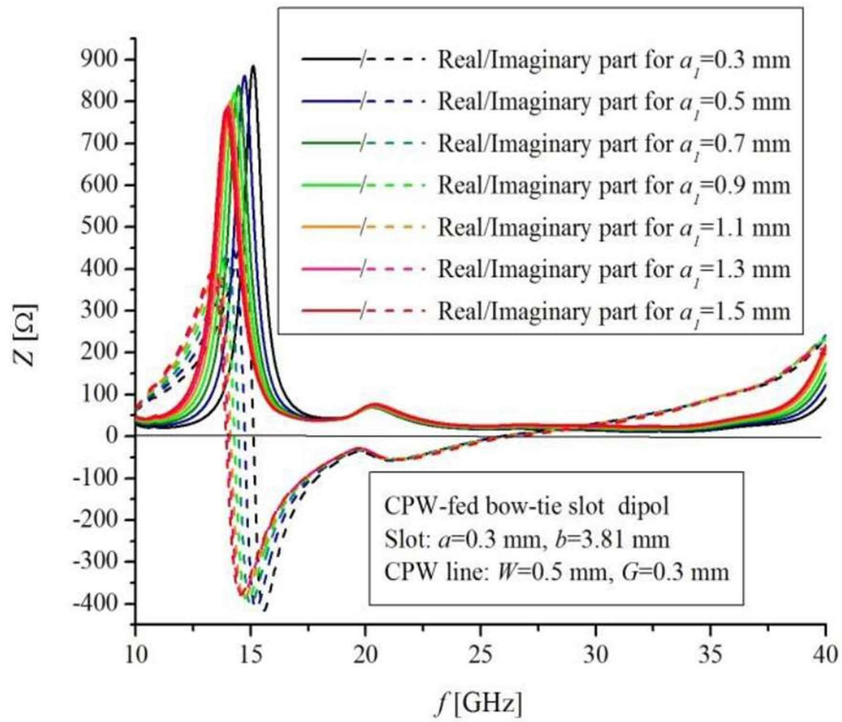

Figure 2. Dipole's impedance versus frequency for different values of slot parameter, co

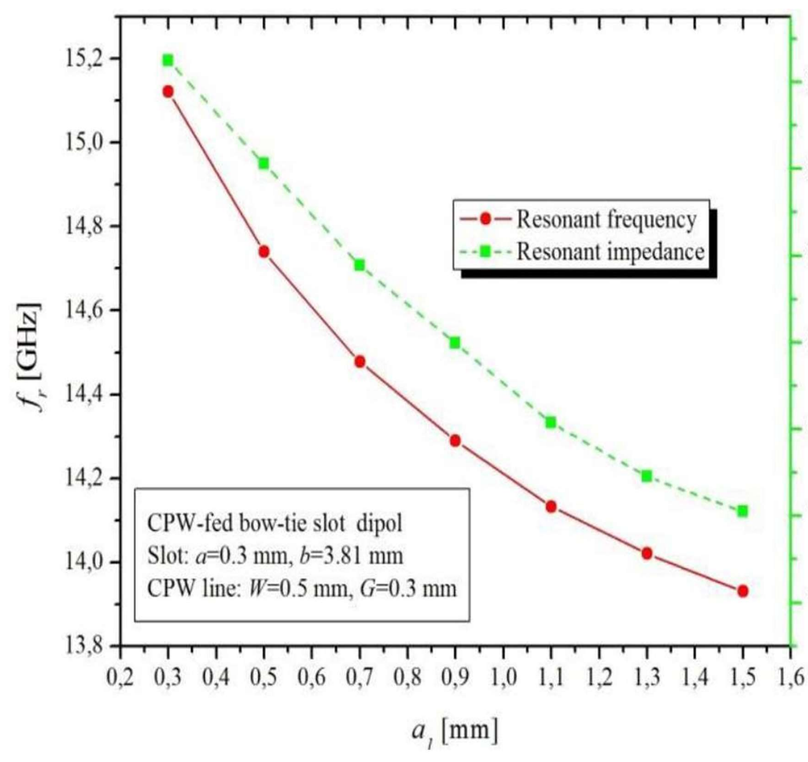

Figure 3. Resonant frequency and impedance of CPW-fed bow-tie slot dipole for the different values of slot parameter, al.

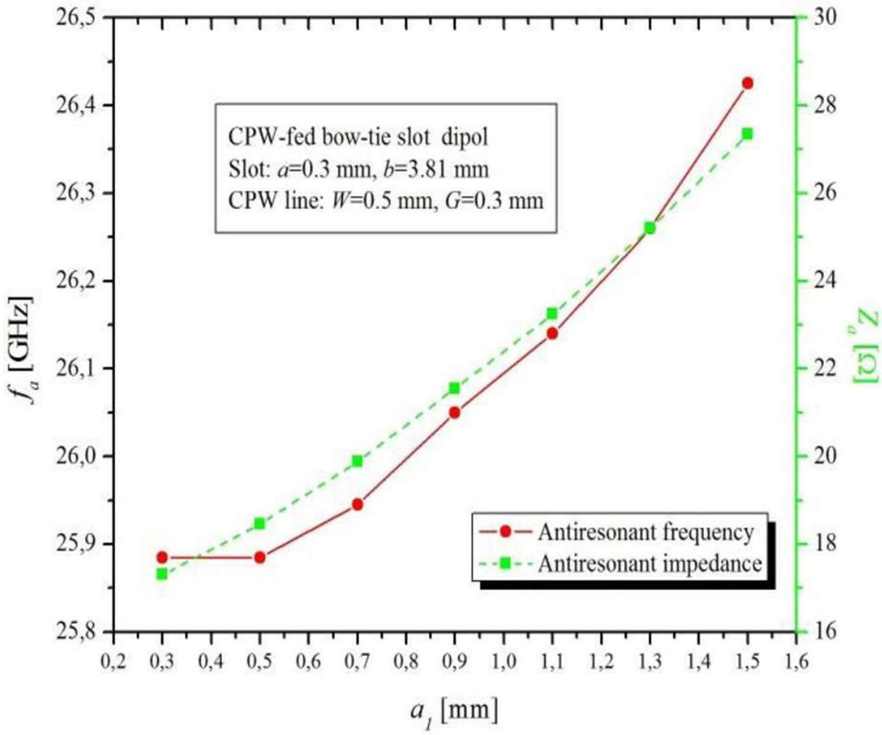

Figure 4. Antiresonant frequency and impedance of CPW-fed bow- tie slot dipole for the different values of parameter, co

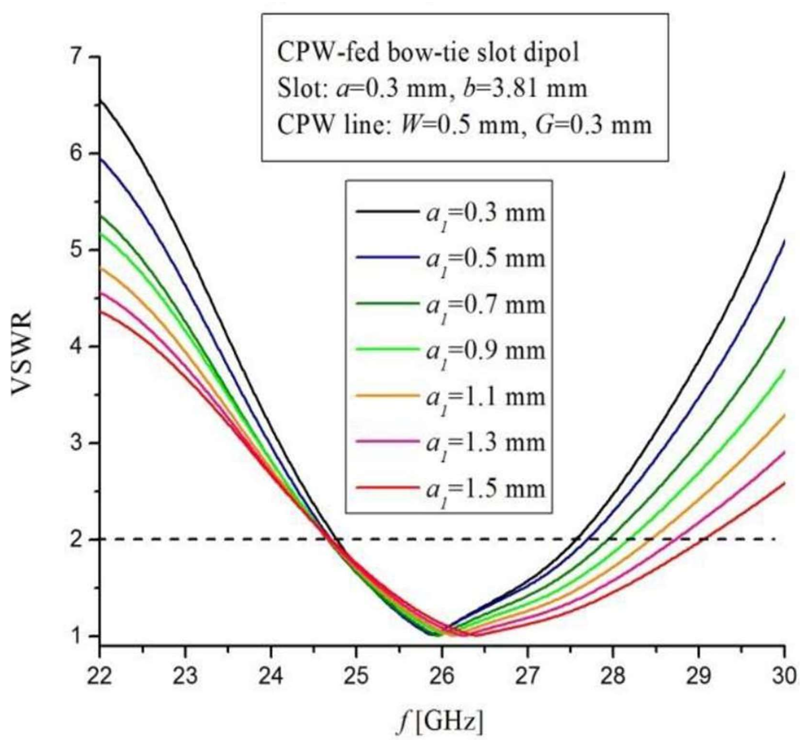

Figure 5. Dipole's VSWR versus frequency for the different values of parameter, al

Slot parameter a_1 [mm]	Bandwidth [GHz] In respect to VSWR < 2	Relative bandwidth in respect to the center frequency [%]
0.3	24.775-27.55	10.6
0.5	24.715-27.685	11.3
0.7	24.67-27.925	12.4
0.9	24.7-28.165	13.1
1.1	24.685-28.42	14.1
1.3	24.7-28.705	15.0
1.5	24.715-29.035	16.1

Table 1. Bandwidth of CPW-FED Bow-tie Slot Dipole for the Different Values of Parameter a_1

resonance. However, the antiresonance frequency features smaller impedance that can be observed in Figure 4. Therefore, it can be concluded that antiresonance frequency is more suitable working band for serial connected CPW-fed bow-tie slot dipoles. Moreover, the smaller value of parameter al causes smaller antiresonance impedance.

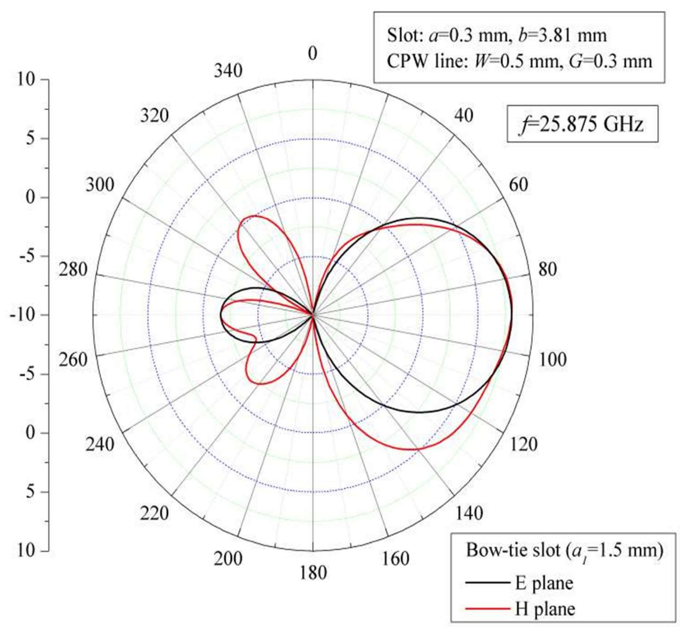

Figure 6. Radiation pattern of the bow-tie slot dipole in E and H- plane

On the other hand, simulated results show that as the slot width al increases, the bandwidth of the slot grows. Figure 5 presents VSWR parameter of bow-tie slot dipole for different slot width a_1 matching the antiresonant impedance Z_a. The numerical values from Figure 5 are presented in Table I together with the bandwidth relative to central frequency.

Analyzing previous presented results, it can be concluded that greater parameter al leads to bigger bandwidth. Therefore, al is adjusted to biggest examined value (1.5 mm) for further analysis. Figure 6 presents simulated E-plane and H-plane radiation patterns and Figure 7 presents simulated co- and cross-polarization of proposed bow-tie slot dipole.

Figure 8-11 and Table 2 show the influence of the slot length b on resonance and antiresonance frequency bands and impedance

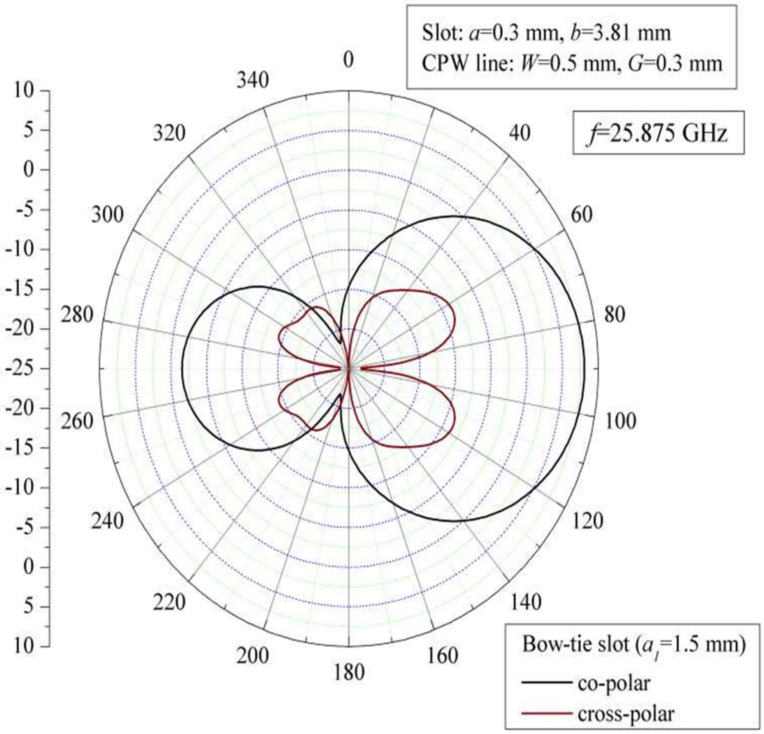

Figure 7. Co-polar and cross-polar radiation pattern of the bow-tie slot dipole

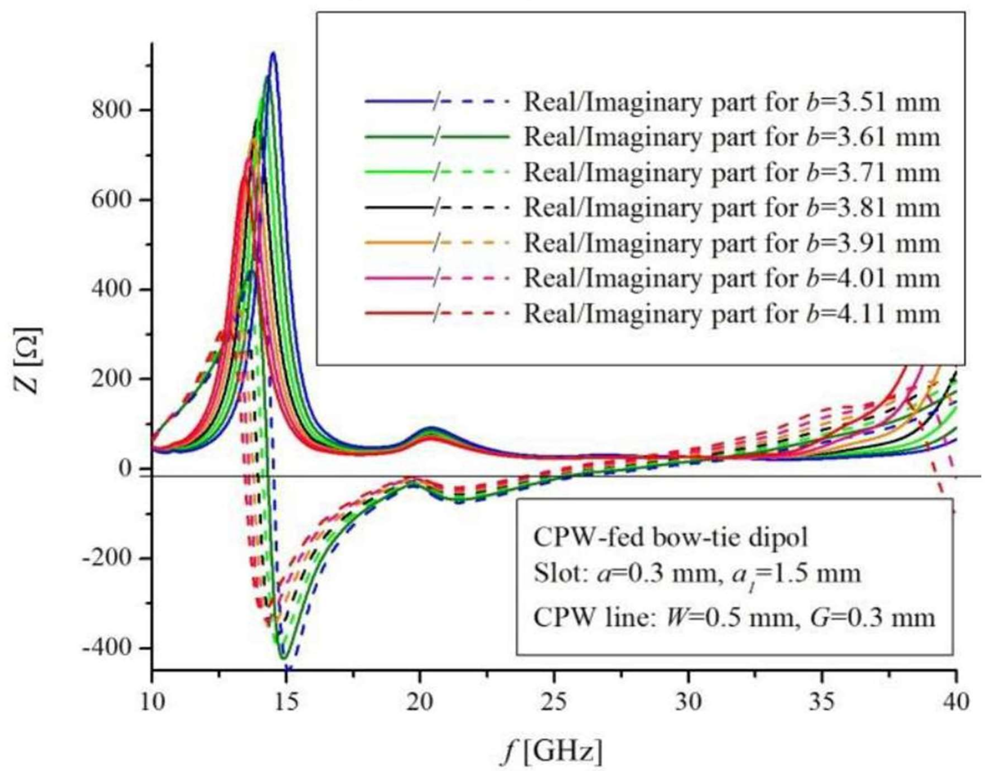

Figure 8. Dipole's impedance versus frequency for different values of slot parameter, b

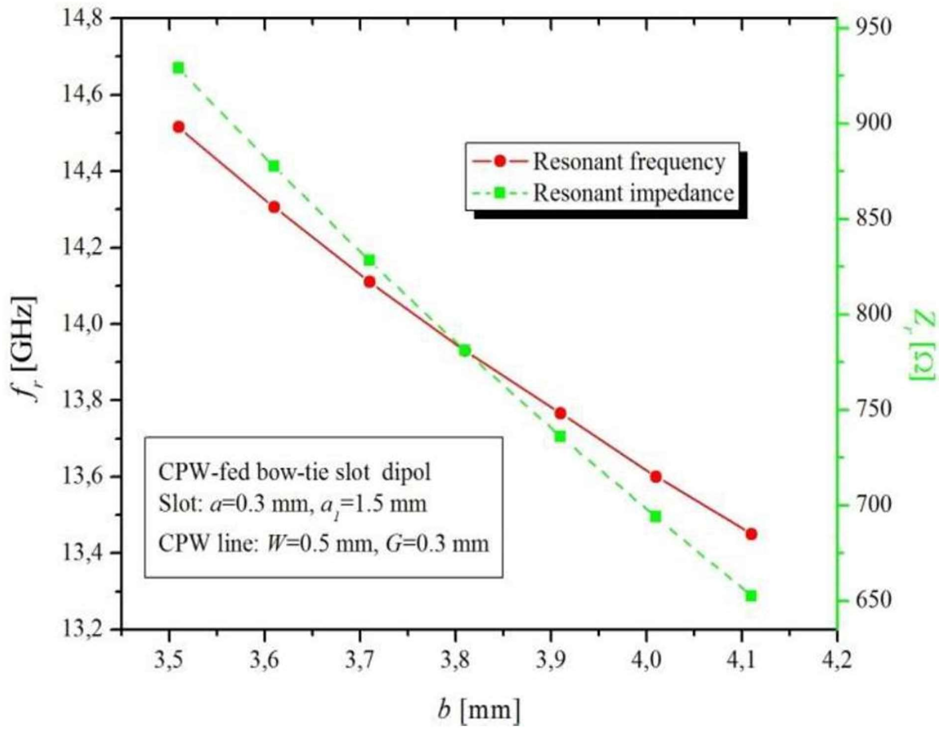

Figure 9. Resonant frequency and impedance of CPW-fed bow-tie slot

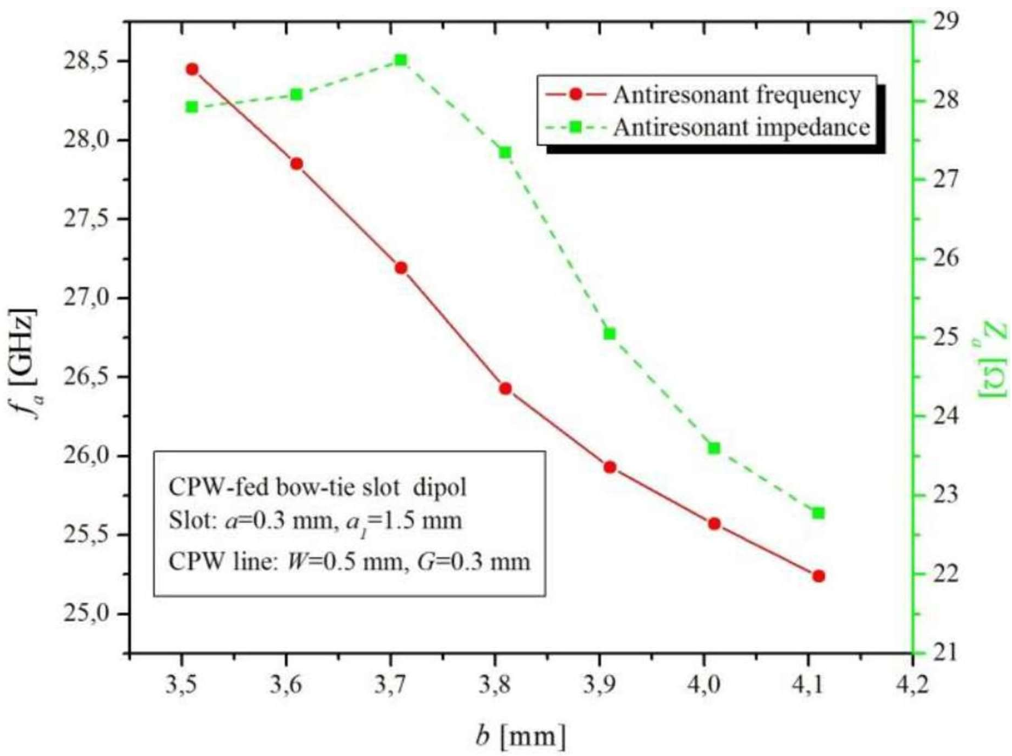

Figure 10. Antiresonant frequency and impedance of CPW-fed bow-tie slot dipole for the different values of slot parameter, b.

of the proposed dipole. Since, the parameter b made a primary impact on resonance frequency band when length b changes from 3.51 mm to 4.11 mm with step 0.1 mm (Fig. 8). For this change of slot length b, resonant frequency has drop for 7.9 % (from 14.5 GHz to 13.4 GHz) while its impedance falls from 925 Ω to 650 (35 %) (Fig. 9). Still, the same change of the slot length *b* causes that the antiresonance frequency fa decreases for 12.3 % (from 28.5 GHz to 25.2 GHz) while the slot impedance falls from 28 Ω to 23 Ω (19.6 %) (Fig. 10). Furthermore, the slot impedance has calm development for both, the real and imaginary part, at the dipole dipole second resonance (antiresonant frequency) (Fig. 8).

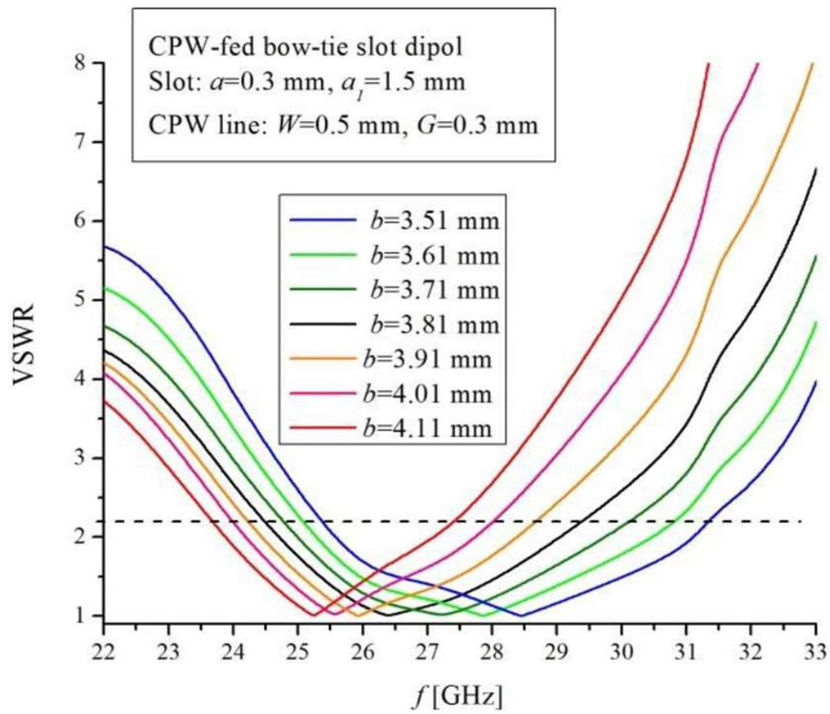

Figure 11. Dipole's VSWR versus frequency for the different values of slot parameter, b

Slot parameter *b* [mm]	Bandwidth [GHz] In respect to VSWR < 2	Relative bandwidth in respect to the center frequency [%]
3.51	25.585-31.09	19.4
3.61	25.3-30.46	18.5
3.71	25-29.725	17.3
3.81	24.715-29.035	16.1
3.91	24.445-28.375	14.9
4.01	24.205-27.73	13.6
4.11	23.89-27.085	12.5

Table 2. bandwidth of CPW-FED bow-tie slot dipole for the different values of slot parameter b

On the other hand, simulated results show that as the slot width al increases, the bandwidth of the slot grows. Figure 5 presents VSWR parameter of bow-tie slot dipole for different slot width al matching the antiresonant impedance Za. The numerical values from Figure 5 are presented in Table 1 together with the bandwidth relative to central frequency

Figure 11 shows VSWR parameter in wide frequency range matching impedance Za at the antiresonant frequency. Table II gives the bandwidth for the different slot length b. With respect to presented results in Figure 11 and table II, it is obvious that the operating bandwidth of a bow-tie slot decreases when the slot length b grows.

4. Conclusion

A CPW-fed dipole with slot of bow-tie shape is proposed for working in the frequency band 24.25-27.5 GHz intended for future 5G cellular networks. The dipole design is compact, with dimensions of only 9.72 x 9.72 x 0.508 mm3. It has a simple geometry and is relatively easy to fabricate because of its single-layer metallic structure. Besides its uniplanar structure that can satisfy the requirements of low profile, the presented simulated results show that proposed dipole features great bandwidth with good impedance matching. A wider bandwidth can be achieved by correctly chosen parameters of a bow-tie slot. It is shown that both parameters al (bigger width of bow-tie shape) and parameter b (length of bow-tie slot) effects the bandwidth of the antenna. The demonstrated results indicate that wider bandwidth can be achieve if the antiresonance frequencies are considered, since there is a calm variation of the impedance, for both the real and imaginary part. Furthermore, slot dipole has significantly smaller impedance at antiresonance frequency band.

Presented results have great importance in antenna array design. In order to obtain desired antenna parameters like radiation pattern, gain, side lobe suppression, etc. a large number of dipoles connected in array are required. Considering serial connection of the slot dipoles and CPW feeding line, their impedance should be small enough (around 20 CI) resulting in acceptable input impedance of the array. Therefore, the adjusting of slot dipole's impedance is a very important step in the beginning of antenna array design.

Further research will be directed to design of a millimeter-wave frequency scanning antenna array for radar sensors [10], which consist of a frequency modulated continuous wave radar in combination with a frequency scanning antenna.

Acknowledgement

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References

[1] Elzwawi, G.H., Mantash, M. & Denidni, T.A. (2017) Improving the gain and directivity of CPW antenna by using a novel AMC surface *IEEE International Symposium on Antennas and Propagation*, San Diego, 2017, pp. 2651–2652.

[2] Ne, A. (1982) Ie, 'Slotted Antenna Array Excited by a Coplanar wave guide,'. Electronics Letters, 18, 275–276.

[3] Bhobe, A.U., Holloway, C.L., Piket-May, M. & Hall, R. (2004) Wide-band slot antennas with CPW feed lines: Hybrid and log-periodic designs. *IEEE Transactions on Antennas and Propagation*, 52, 2545–2554.

[4] Joubert, J., Vardaxoglou, J.C., Whittow, W.G. & Odendaal, J.W. (2012) CPW-fed cavity-backed slot radiator loaded with an AMC reflector. *IEEE Transactions on Antennas and Propagation*, 60, 735–742.

[5] Marcus, M.J. (2015) 5G and 'IMT for 2020 and beyond,'. IEEE Wireless Communications, 22, 2–3.

[6] Milosevic, V., Jokanovic, B., Boric-Lubecke, O. & Lubecke, V.M. (2017). Key microwave and millimeter wave technologies for 5G radio. In: (edited by R. Budiatru, I. Aldmour) *IGI Global*, 70–104.

[7] Hong, W., Baek, K. & Ko, S. (2017) Millimeter-wave 5G antennas for smartphones: Overview and experimental demonstration. *IEEE Transactions on Antennas and Propagation*, 65, 6250–6261.

[8] Milli, M., Negia, A. & Milovanovia, B. (2017) *Study of dielectric substrate effect on modelling CPW-fed slot antenna arrays 13th International Conference TELSIKS*, Nis, 2017, pp. 105–108.

[9] Pro, W.-D., v.10.0. WIPL-D Team.

[10] Schafer, J., Gottel, B., Gulan, H. & Zwick, T. (2018). Integrated planar 122 GHz FMCW radar with frequency scanning antenna, *Wireless Sensors and Sensor Networks (WiSNet) IEEE Topical Conference on,* pp. 41–43.