

Compact design of stair shape patch for short range and lower 5G systems



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ABSTRACT

A new stair with four steps shape compact antenna is proposed for lower fifth generation and short ranges wireless communications. The presented design is covering a radio frequency (RF) band starting from 3.07 GHz to 11.4 GHz. This monopole consists of a single layer of stair shape printed on a dielectric material of Rogers Duroid RT5880Lz with relative permittivity of $\epsilon_r=1.96$ and loss tangent δ of 0.0009. Also, the design is characterized by miniaturized structure size $20 \times 24 \text{ mm}^2$ and maximum power gain of 5.6 dB. The antenna has been designed and optimized using an industrial standard simulation software (CST Microwave studio and HFSS for verifications).

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1. Introduction

In the next few years, the world mobile data traffic is expected to grow by more than 45%, which means an increment by ten times between 2016 and 2022. The enormous growth is because of the dramatic increase in number of wireless devices which expected to reach 29 billion internets of things devices within few years (Dateki et al., 2016; Al-Saif et al., 2018). Thus, the more frequency bands are needed to overcome the high demand in the fifth wireless generation. Therefore, lower 5G and higher 5G spectrum bands are needed; however, lower 5G frequency bands are more appropriate for earlier deployment due to better wave propagation properties, some others. These bands range between 2 GHz and 6 GHz such as from 3.3 GHz till 4.2 GHz, from 4.4 GHz till 4.99 GHz (Obile, 2016). In the Table 1 list of initial lower 5G bands in different regions.

Several monopole antennas that cover such bands have been proposed previously (Huawei, 2018; Ren and Chang, 2006; Kim and Jee, 2007; Abbosh and Bialkowski, 2008; Ebrahimi et al., 2010; Xu et al., 2013; FCC, 2002). The majority of these ultra wide band designs have some key shortages in the performance. For instance, in some of them the bandwidths do not include the entire FCC band from 3.1 GHz to 10.6 GHz allocated for such applications. In other cases, the power gain not high which will negatively affect the wireless system battery life. In

addition, some designs have relatively large structure size or complicated design which increase the fabrication cost. The proposed monopole antenna has overcome these challenges and have high performance in terms of wider operating frequency from 3.07 GHz till 11.4 GHz based on -10 dB criteria with good impedance match. Also, the radiation pattern is omni-directional shape which means the antenna is independent of the placement position in the wireless system. Also, the power gain reach over 5.6 dB during the operating band with simple and small structure size. More details about the suggested antenna are presented in the next section.

Table 1: Regions and lower 5G frequency bands (Obile, 2016)

Region	Frequency Band (GHz)
Europe	3.4 - 3.8
	3.6 - 3.6
China	4.4 - 4.5
	4.8 - 4.99
Japan	3.6 - 4.2
	4.4 - 4.9
South Korea	3.4 - 3.7
USA	3.1 - 3.55
	3.7 - 4.2

2. Proposed monopole structure

The design antenna is compact with total size $20 \times 24 \text{ mm}^2$ printed on a substrate of Rogers Duroid RT 5880Lz with relative permittivity and dielectric loss tangent of 1.946 and 0.0009, respectively. The top view of the proposed antenna is shown in Fig. 1. Table 2 presents the parameters of the stair shape patch after optimization. The antenna has been designed, and simulated using an industrial standard simulation software called CST Microwave studio

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and High frequency structure simulator HFSS for results verifications.

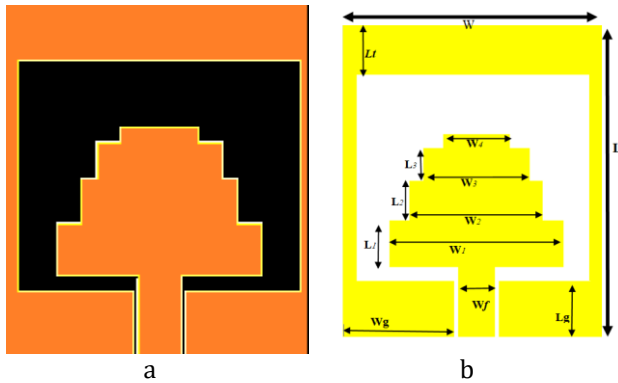


Fig. 1: (a) top view of the proposed antenna (b) the optimized geometry of the proposed design with labeled with parameters

Table 2: The presented monopole parameters in mm

L	W	H	Wf
24	20	1	2.7
Lf	Lg	Wg	Ws
5.5	4.5	8.3	1
Lt	W1	L1	W2
4	13	3.5	10
L2	W3	L3	W4
3	8	2.5	5

The design is a simple single layer patch and it is similar to a stair shape with four steps fed by a 5.5 mm long microstrip line and 2.7 mm wide. The patch has an input impedance of 50 ohms. The antenna has been studied, investigated, and optimized in terms of crucial parameters such as microstrip feeding line width size, substrate dielectric material, and patch steps sizes. More discussions about the simulation results and antenna performance clarified are in the next section.

3. Discussions of the simulation results

In general, a narrow band antenna has a single resonant frequency whereas multiple resonant frequencies result in wide bandwidth. Hence, designing a patch with several overlapped resonant frequencies will produce an ultra-wide band design (Gautam et al., 2013). The proposed design has three resonant frequencies which 3.77 GHz, 7.35 GHz, and 10.22 GHz forming a wide bandwidth of 8.33 GHz from 3.07 GHz till 11.4 GHz as shown in Fig. 2. The monopole has been studied, investigated, and optimized in terms of crucial parameters such as microstrip feeding line width size, and substrate dielectric material. Fig. 3 displays the reflection coefficient versus the operating frequency for several feeding line width which are 2.5 mm, 2.7 mm, and 2.9 mm. it has been noticed that S11 at wf= 2.7 mm has a wider bandwidth based on -10dB standard criteria whereas at 2.5mm and 2.9mm the design has lower impedance matching. Also, the different

substrate dielectric materials have been examined for optimizations which are Polyimide, FR4, and Rogers Duroid RT5880LZ with relative permittivity ϵ_r of 3.5, 4.3, and 1.946, respectively. Fig. 4 shows Reflection coefficient (dB) as a function of operating frequency (GHz) using different substrate dielectric materials (Polyamide, FR4, and Rogers Duroid RT 5880Lz.

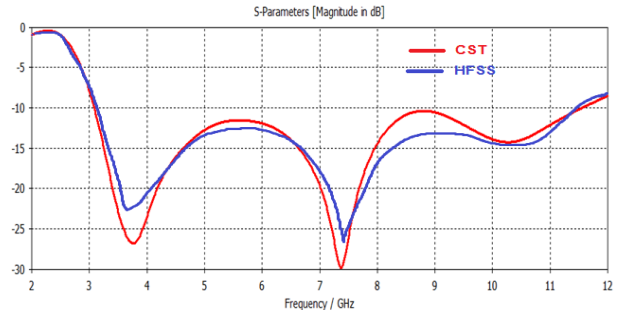


Fig. 2: Simulated reflection coefficient S11(dB) versus operating frequency (GHz) from CST and HFSS showing good matching between the two plots

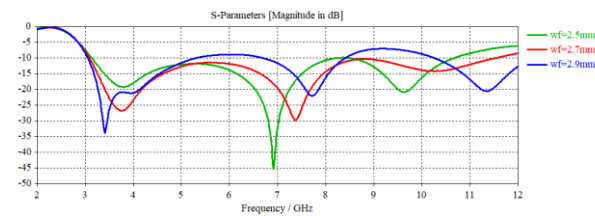


Fig. 3: Optimizing the width parameter of the feeding line (wf) for the presented design

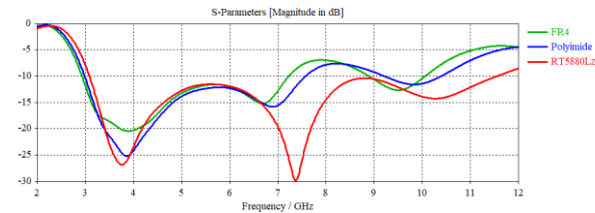


Fig. 4: Reflection coefficient (dB) as a function of operating frequency (GHz) using different substrate dielectric materials (Polyamide, FR4, and Rogers Duroid RT 5880Lz

Fig 5 shows the normalized radiation pattern to the maximum value of the presented monopole at the three resonant frequencies 3.77 GHz, 7.35 GHz, and 10.22 GHz. It illustrates the radiation pattern for the two main planes, the E or elevation plane and H or azimuth plane in polar forms. It can be observed that during the wide operating frequency, the antenna radiation pattern at the H plane is an omni-directional shape and the E plane is bi-directional pattern with minor distortion. Consequently, the proposed stair shape patch radiates in an omni-directional pattern which makes the antenna to be independent of the placement position within the wireless system. Fig. 6 reveals the maximum power gain in dB as a function of the operating frequency in GHz. The design has a high gain relatively which reaches 5.7 dB.

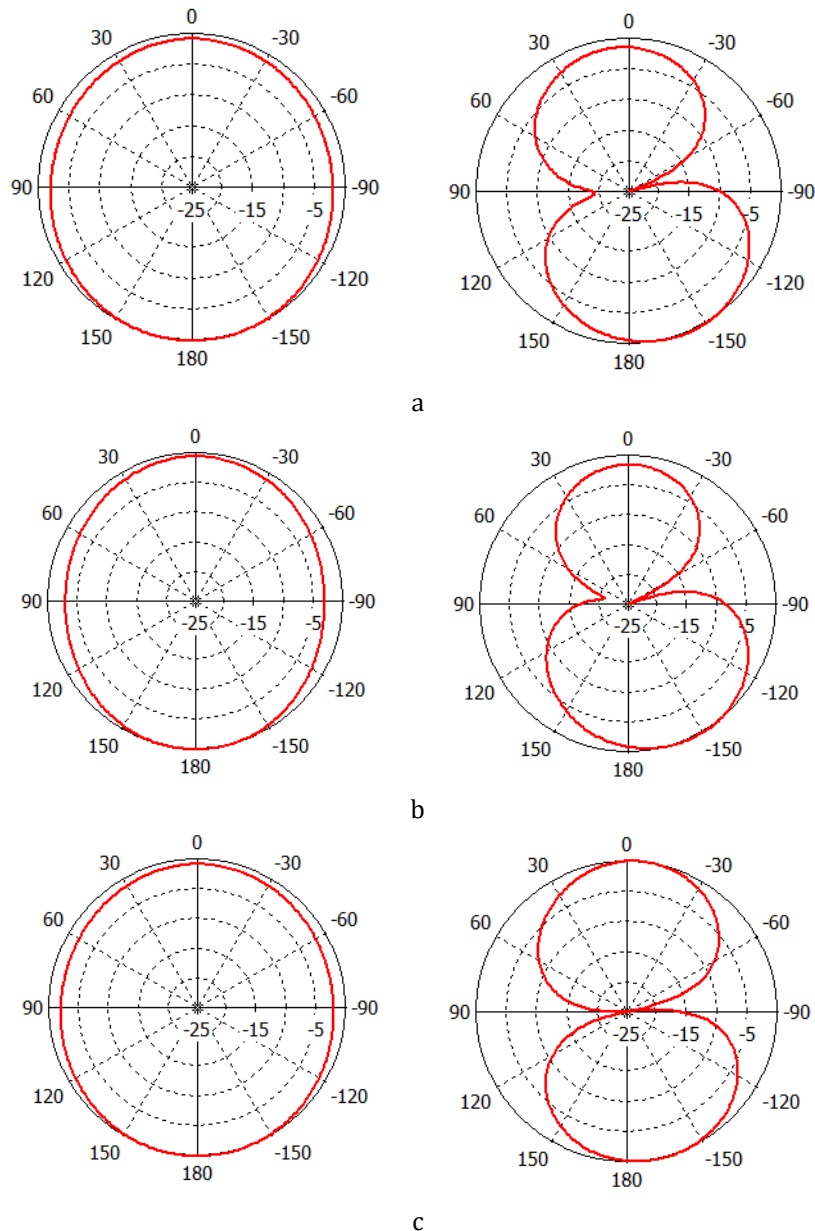


Fig. 5: The simulated normalized radiation pattern for E and H planes in polar form at the resonant frequencies (a, b, and c)

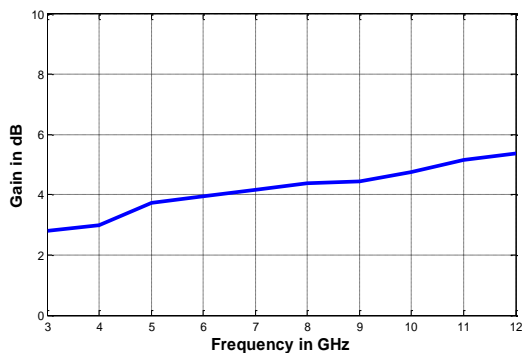


Fig. 6: The power gain in dB versus the operating frequency for the proposed antenna

4. Conclusion

A new miniaturized stair shape design is presented for lower fifth generation and short ranges wireless systems. The antenna is miniaturized and it has a size of $20 \times 23 \times 1 \text{ mm}^3$. The

proposed monopole has a high performance in terms of operating frequency which is from 3.07 GHz to 11.4 GHz covering beyond the FCC UWB set for such applications. In addition, the design radiates in an omni-directional pattern; consequently, the monopole is independent of the placement orientation inside the system. Finally, the proposed patch has higher performance compared to many previously published antennas that sorts it to be more suitable for compact 5G communication systems.

Compliance with ethical standards

Conflict of interest

The authors declare that they have no conflict of interest.

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