Bulletin of Electrical Engineering and Informatics
Vol. 12, No. 5, October 2023, pp. 2846~2851
ISSN: 2302-9285, DOI: 10.11591/eei.v12i5.4694

Dual band antenna in licensed and unlicensed frequency bands based on superformula for 5G applications

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Article Info

Article history:

Received Sep 3, 2022
Revised Nov 25, 2022
Accepted Dec 21, 2022

Keywords:

Dual band
Fifth generation
Superformula

ABSTRACT

In this paper, the design and analysis of dual bands antenna is carried out. The ranges of frequencies are below 6 GHz and above 24 GHz. The superformula was used to design the proposed antenna where the curve profile of the proposed antenna is obtained by adjusting the six different parameters of the super-formula. The antenna shape likes the sunflower was mounted on flame retardant level 4 (FR4) substrate of dimensions of 32×32×1.5 mm^3 and fed by a microstrip. The antenna is simulated using a computer simulation technology (CST) simulator. Results of the simulation showed that the antenna works in the licensed band (5.5–5.8 GHz) and the unlicensed band (24-40) GHz with voltage standing wave ratio (VSWR) less than 2 and return loss below -10 dBm. Also, the proposed design showed better performance than the normal ellipse-based antenna design with the same antenna dimensions.

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1. INTRODUCTION

The increasing of number of subscribers with their smartphones and the huge number of internet of things devices need large capacity and faster data rates. The fourth generation (4G) technology is unable to provide this need. Therefore, the fifth generation (5G) technology has been proposed to overcome the limitation of 4G [1]. The 5G mobile communication technique uses multiple antennas at the transceiver to increase the capacity of the channel without the necessity for more frequency bandwidth and transmitted power [2]–[12]. This goal can also be achieved by design single antenna to operate at multiple frequencies in different bands [13], [14].

The characteristics of the patch antenna represented by the low cost, easy fabrication and light weight make it a good candidate for wireless communication. Also, the patch antenna is considered a very much useful component in modern communication because of it can be designed to resonate at multiple frequencies. The requirements of 5G applications demands represented by low latency and high quality transmission motivate the researchers to go up the electromagnetic spectrum of the unused millimeter-wave (30–300 GHz) and exploiting their widely available bandwidth for high data rate transmission [15]–[19]. The International Telecommunications Union (ITU) allocated the bands of frequency centred at 0.028, 0.038, 0.060, and 0.073 THz for wireless communication of 5G mobile systems [20]. Since the availability of unlicensed wide frequency range at high frequency but it is not appropriate band for long range wireless system because of the radio frequency signal attenuation caused by the atmosphere particles represented by the molecules of oxygen [21].

Nowadays, many designs of antennas for 5G applications have been provided. A dual band multiple-input and multiple-output (MIMO) antenna at the (28/38 GHz) band was introduced in [22]. There are two arrays with three elements for each array are utilized to realize this antenna. According to Imran *et al.* [23], a microstrip patch antenna was proposed to operate in a dual-band (38/54 GHz). Also, a dipole antenna with circular polarization had been proposed based on a waveguide of printed ridge gap for (29.5–37 GHz) frequency band operation [24]. A MIMO-based antenna for 5G communication systems was presented based on the pattern diversity and polarization for operating in the band of frequency of (34-38 GHz) [25].

Abdullah *et al.* [26] presented the design of a triple band antenna at frequencies of 2.45 GHz, 4.5 GHz, and 5.725 GHz, this antenna was designed for harvesting the energy. The simulated results showed an acceptable performance in terms of the voltage standing wave ratio (VSWR) and the return loss. But, this antenna operates in the licensed frequency band only. According to Alshaikhli *et al.* [27], a triple band antenna (3.3 GHz, 4.5 GHz, and 5.8 GHz) was proposed for the applications of worldwide interoperability for microwave access (WiMAX), data link system for unmanned aerial vehicles (UAV) drones, and wireless local area network (WLAN). The design of this antenna depended on the slits in the ground layer to enhance the electrical characteristics of the antenna. Actually, the standard shape was adopted in the design and the operation bands are in the licensed bands.

The superformula was used to design antennas in the frequency range under 6 GHz. The literature contains enlightening examples. One of these was the examination of bio-inspired microstrip antennas using the superformula to obtain forms found in nature by Serres *et al*. [28]. They looked at fractal-like elements in the forms of leaves. Results obtained in leaf-shaped antennas were shown to be more effective. Another example is the ultra-wideband microstrip patch antenna presented by Omar *et al.* [29] that has a bandwidth of (3.1–10.6 GHz). The patch's circumference is circular and resembled a sawtooth. The diameter of the super-shaped patch was less than that of the conventional patch of circular shape [29].

The superformula was often used in antenna configurations for MIMO systems. Using superformula, Naser and Dib [31] created a single-pole antenna of ultra-wideband. The developed antenna was shown to have additional benefits such as high steady gain, compactness, and nearly constant group delay [30]. Following that investigation, this group of researchers developed a MIMO configuration by mounting on the same substrate the ultra-wideband antennas of two super-shaped. Then, both of the examined antennas were transmitted over a bandwidth of 3.1 GHz to 12 GHz. Most of the previous research did not address the design of a dual-band antenna within two widely spaced frequency bands. In this work, the superformula is used to design an antenna in two widely spaced frequency bands, the first band in the licensed region, which is under 6 GHz, and the second band in the unlicensed region, which is from (24-40) GHz. To be compatible with the 5G bandwidth.

The other parts of this paper are: section 2 explains the process for designing the antenna at the desired frequency based on the superformula. The simulation of the suggested antenna in computer simulation technology (CST), together with the findings and discussions, are presented in section 3. This paper is concluded in section 4.

2. PRINCIPLES AND DESIGN OF THE PROPOSED ANTENNA

The procedure of the suggested design will be illustrated in this section. CST microwave studio suite is used to build and simulate the dual band microstrip antenna because of the accuracy and design elements of this software are quite good. The ground metallic layer, which is the lowest layer, is constructed of annealed copper with a height of t=0.035 mm. The second layer uses an insulator as a substrate layer will be on the top of the ground layer and is constructed of flame retardant level 4 (FR4) material. Many printed circuit board (PCB) antennas use the FR4 lossy as substrate because of its very low cost, wide availability on the local market, and excellent mechanical qualities. This makes the FR4 material a top choice for a variety of applications involving electronic components. There is a lot of interest in reducing the cost of these systems as more and more. For microwave circuits and antennas, employing FR4 instead of more expensive substrate types could result in significant financial savings. The thickness of 1.5 mm is used for the substrate layer. The microstrip patch, which is also formed of annealed copper, is the third and final layer of the suggested design. A microstrip feed line is used for antenna feeding. The superformula will be used for design the patch layer of the presented antenna.

The superformula firstly developed by Gielis [32], in which he claimed that a function can be used to formulate the closed curves. This function is called superformula represented in (1). There are six parameters in this equation (a, b, m, n1, n2, n3) [32]. Variable values of these parameters give different nature like shapes such as flowers and leafs. Since, not all of them can be used to design a patch antenna because of the symmetry properties. The radius of the shape is calculated as in (1):

$$r(\theta) = \left(\left| \frac{\cos\left(\frac{m}{4}\theta\right)}{a} \right|^{n_2} + \left| \frac{\sin\left(\frac{m}{4}\theta\right)}{b} \right|^{n_3} \right)^{\frac{-1}{n_1}} \quad (1)$$

Then, x and y coordinates are calculated as (2):

$$x = r(\theta) \times \cos(\theta)$$

$$y = r(\theta) \times \sin(\theta) \quad (2)$$

In our design, we added two parameters K_x and K_y in calculation of x and y. These two parameters provide more flexibility to resize the antenna shape in x direction or y direction or both.

$$x = K_x \times r(\theta) \times \cos(\theta)$$

$$y = K_y \times r(\theta) \times \sin(\theta) \quad (3)$$

The first step in figuring out the superformula's parameters is to create a circular patch antenna with the required resonance frequency in mind. The resonance frequency of 5.7 GHz is used in this work for a variety of wireless communication technologies. For this fundamental frequency, the size of a circular patch antenna is utilized to calculate the superformula's a and b parameters. The symmetry and optimization processes are used to determine the other m, n1, n2, and n3 parameters. These characteristics can be changed to produce a variety of forms.

We've suggested that this design resemble a sunflower. The superformula parameters (a, b, m, n1, n2, n3) are so chosen as follows: (1, 1, 16, 8, 8, 8). The suggested antenna is simulated on a 1.5 mm thick FR4 substrate with $\varepsilon_r = 2.2$. Figure 1 depicts the modelled antenna created using the superformula. The antenna has been designed with 32×32 mm dimensions. To obtain a good return loss in the dual bands, the patch size is then scaled by $K_x = 10$ and $K_y = 12$. The input impedance is set to 50 ohms when using the microstrip feeding method.

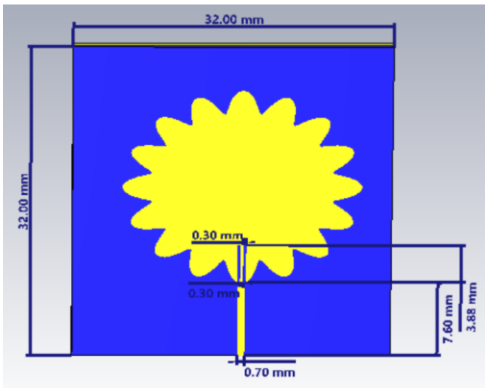


Figure 1. The structure of the proposed antenna with (a=b=1, m=16, n1=8, n2=8, n3=8)

3. SIMULATION RESULTS AND DISCUSSION

The design of sunflower like antenna at 5.75 GHz and 26.6 GHz and obtained results have been discussed in this section. The proposed antenna is designed and simulated using CST software to exhibits its simulation results. The profile curve was drawn based on the superformula and the patch was created by extruding process. Figure 2 shows the reflection coefficient or S11 of this antenna. It is clear that the designed antenna at the dual bands satisfied the requirement level of -10 dB in which it is about -20 dB and -40 dB for lower and upper bands, respectively.

Figure 3 depicts the proposed antenna's VSWR. The reflected power from the antenna is described by VSWR. The antenna is ideally matched to the source for lower VSWR, more power is also sent to the antenna via transmission line without experiencing a mismatch effect. When the VSWR value is less than 2, the antenna matches very well with the transmission line and little would be gained by impedance matching. If the VSWR value is 1, there is no reflected power from the antenna, which is perfect. The suggested antenna achieves good impedance matching and a VSWR value of less than 2.

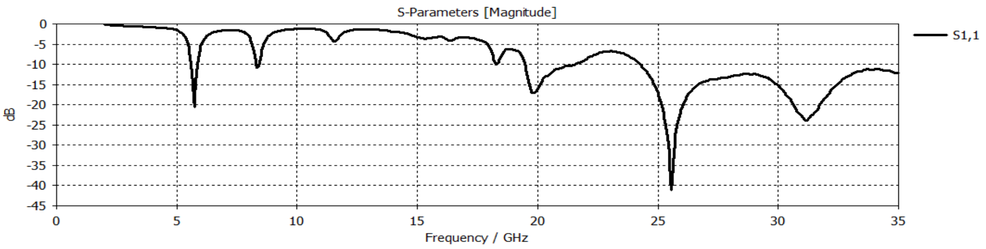


Figure 2. The S-parameters of the proposed antenna

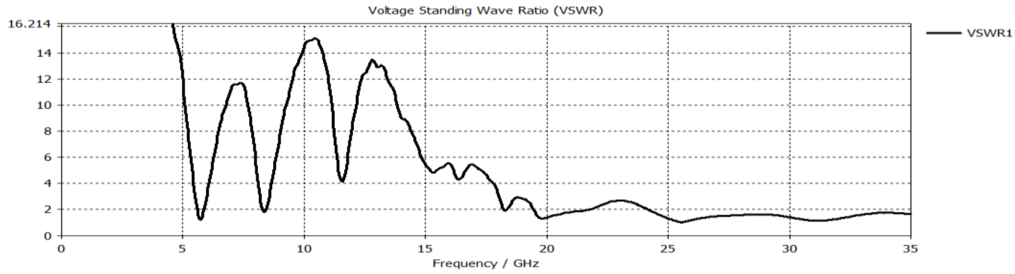
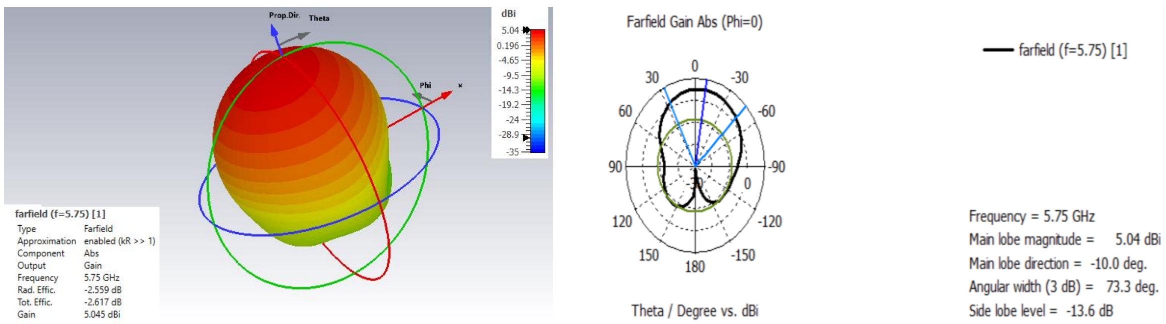


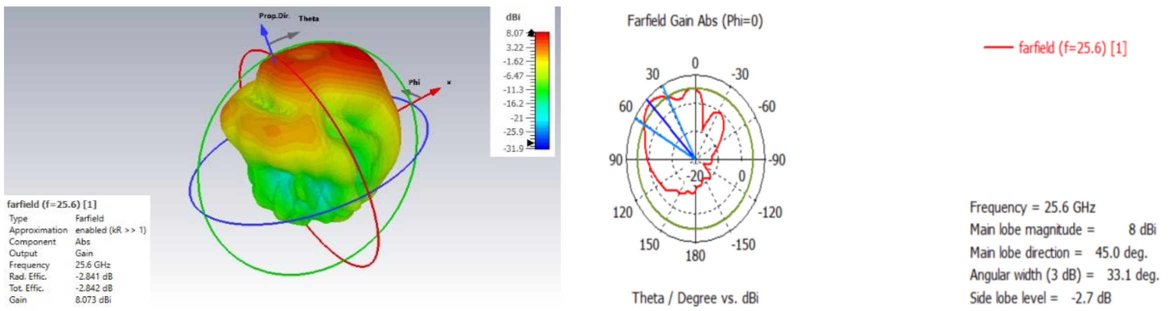
Figure 3. The VSWR of the proposed antenna

The simulated radiation patterns of the proposed antenna are shown in Figure 4. Figure 4(a) illustrates the radiation pattern in three dimensional and two dimensional at frequency of 5.75 GHz while Figure 4(b) shows the radiation pattern at frequency of 26.6 GHz. Clearly, the gain values are 5 dBi and 8 dBi for these different frequency bands in which they are in the acceptable level.

Finally, a comparison of a patch antenna based on the proposed shape with an antenna based on normal ellipse shape for the same dimensions. Figure 5 shows the ellipse shape based antenna where Figure 5(a) represents the structure of this antenna and Figure 5(b) displays the S-parameter of this antenna. The comparison between Figures 2 and 5 illustrates that the superformula based antenna has better performance than the normal based antenna in term of the S-parameter.

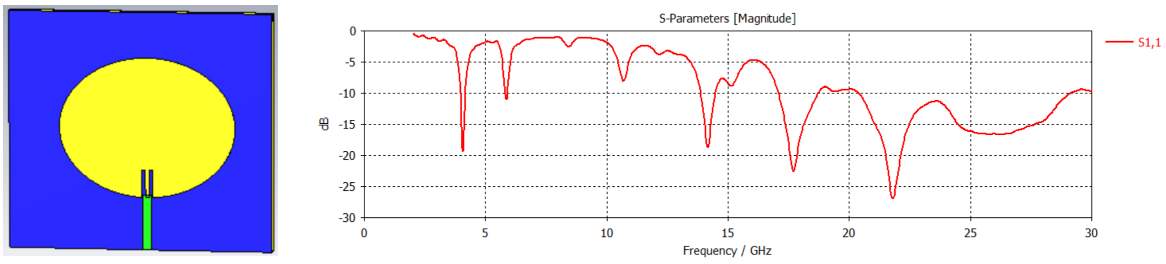


(a)



(b)

Figure 4. The radiation patterns of the proposed antenna at; (a) 5.7 GHz and (b) 25.6 GHz



(a) (b)

Figure 5. The normal ellipse-based antenna (a) the structure and (b) the S-parameter

4. CONCLUSION

The dual bands antenna has been proposed based on the superformula. A microstrip is used to excite the proposed antenna and FR4 material is used as a substrate with $\varepsilon_r = 2.2$. The simulation results have been presented and discussed. The proposed antenna design showed good behavior in the licensed and unlicensed frequency bands, as it gave a value of S-parameter less than -10 dBm. Also, the gain values are 5 dBi and 8 dBi in the licensed and unlicensed frequency bands, respectively. Over the operational frequency ranges, the proposed antenna displayed a virtually consistent radiation pattern and achieved a very good ranges of gain. In addition to that, the designed antenna in this paper showed an S-parameter better than the normal ellipse-based antenna.

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