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Design of substrate integrated waveguide with Minkowski-Sierpinski fractal antenna for WBAN applications

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ABSTRACT

This paper presents a new design of patch antenna using Minkowski-Sierpinski fractal technique with substrate integrated waveguide (SIW) to resonate at 60 GHz. The antenna is proposed to be used for wireless body area network applications (WBAN). The proposed antenna is implemented using Rogers 5880 substrate with permittivity of (ε_r) of 2.2 and loss tangent is 0.0004, height of the substrate is 0.381 mm. Computer simulation technology-Microwave Studio (CST-MW) is used to simulate the proposed antenna. The simulated results show a wide bandwidth of 3.5 GHz between the ranges of (58.3-61.7) GHz, with a good return loss of more than -10 dB. A simulated gain of 7.9 dB is achieved with a linear antenna efficiency of 91%. This proposed antenna is used to improve the quality of radiation pattern, bandwidth, and gain at millimetre wave (mm-Wave) band for WBAN applications.

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1. INTRODUCTION

Body-implanted electronics came into existence when the first pacemaker was invented in the 1950s [1]. This healthcare innovation exposed the potential and revealed vast opportunities in the field of implantable electronic devices, enabling new ways of diagnostics and treatment. Wireless implantable bioelectronics is a fast-growing field having many potential applications in medicine, clinical research, professional sports, occupational health, and defence while maintaining a patient's mobility [2-4]. The term "wireless body area network (WBAN)" refers to the networking process that is related to human himself/herself and or human to another human network oneself and to other persons networking [5]. Then rise in interest can be seen in this technology from academics and industries [6-9]. During the last twenty years [10-12], an amount of investigation has been observed in the area of WBANs.

Most of researchers use high frequency rather than low frequency in order to overcome the disadvantages of low frequency such as interfacing and low penetration depth [13, 14]. Signals are supposed to be intermixed due to long-distance and interfere among other frequencies. This happens in order to control radiation. The need is to increase the size of antennas with the objective of achieving large wavelength [15, 16]. The situation reverses when the frequency of bands is higher. Selection of frequency seems like a compromise between propagation loss, the interference strength, antenna and the rates for data. In recent studies, these two bands of ISM and UWB have widely implemented in the WBAN band applications [17, 18].

The recent research suggested that WBAN networks at 60 GHz will perform much better than those at low frequencies, in terms of coexistence with neighbouring WBAN networks, and immunity from interference and interference in other systems [19, 20]. These benefits are expected to be obtained through more advanced BAN and higher-gain antennas, some of which are reproducible. First fractal geometry was proposed by Mandelbrot *et al.* [21, 22]. Since that time, widespread applications have been found in fractal shapes. This topic has been discussed by several branches of science and engineering that have included antenna design in their discussion [23, 24]. Fractal forms have already been shown to be very efficient in the design of compact antennas with a low profile. More than that, the increase in multiband operation, bandwidth and enhance gain are the other characteristics. There are different shapes of fractal geometries have been calculated such as Sierpinski gasket and Minkowski carpet [25].

In this work, Minkowski-Sierpinski fractal technique with SIW resonate at 60 GHz for WBANs is proposed. The results obtained of the proposed design are 7.9 dB gain, 8.51 dBi directivity and -18.65 dB return loss. The results have compared with other designs and have shown improvement of 70% gain, 12% efficiency, and 20% reduced the size.

2. RESEARCH METHOD

The general structure of SIW is shown in Figure 1. It consists of a rectangular waveguide, two rows of periodic holes, and a substrate at the top and bottom of ground planes [26, 27]. As can be seen from Figure 1, the parameters of the SIW should be taken in consideration. The width between the vias can be found by [28]:

$$a_R = w - \frac{D^2}{0.85\,S^2} \quad (1)$$

where a_R is the waveguide width, D is the diameter of the vias, and S is the spacing between each vias. The diameter of the vias and the spacing can be calculated using [28]:

$$D \leq \frac{\lambda_g}{5} \quad (2)$$

$$S \leq 2D \quad (3)$$

$$a_R = \frac{a}{\sqrt{\varepsilon_r}} \quad (4)$$

where a is the width of the rectangular waveguide standard, and λ_g is the guided wavelength of the SIW [28]:

$$\lambda_g = \frac{2\pi}{\sqrt{\frac{\varepsilon_r (2\pi f)^2}{c^2} - \left(\frac{\pi}{a}\right)^2}} \quad (5)$$

where f is the desired frequency, c is the speed of light, and ε_r is the substrate permittivity.

The proposed antenna is designed using Roger 5880 substrate. Figure 2 shows the geometrical structures of the SIW Minkowski-Sierpinski carpet fractal antenna at 60 GHz. The substrate using Roger 5880 substrate with ε_r=2.2 and thickness of substrate is 0.381 mm, while the patch and ground are using copper with thickness h=0.035 mm. By using (1) to (5), the diameter, spacing of holes, and the width between holes can be determined at desired frequency of 60 GHz. Table 1 summarizes the final dimension of the proposed antenna.

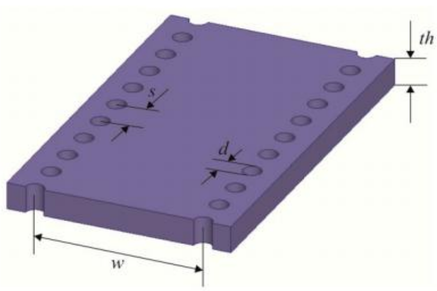
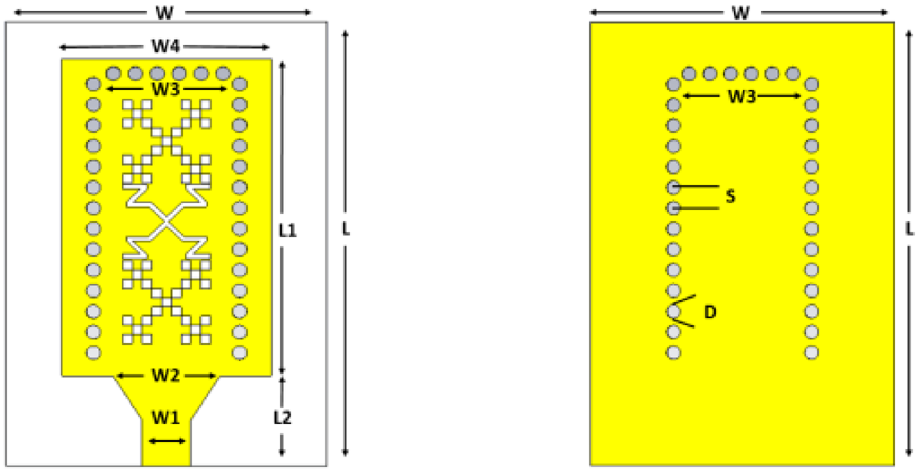


Figure. 1. The prospective general structure of a substrate integrated waveguide [28]



(a) (b)

Figure 2. The proposed structure of SIW with Minkowski-Sierpinski fractal antenna,
(a) Top view, (b) Bottom view

Table 1. The final parameters values of the proposed antenna with SIW (all dimensions in mm)

Variable	Patch	Substrate	Ground
W	-	6.5	6.5
L	-	9.6	9.6
W3	3	3	3
L1	6.9	-	-
L2	0.98	-	-
W2	2.2	-	-
W1	1	-	-
S	0.45	0.45	0.45
D	0.3	0.3	0.3
h	0.035	0.381	0.035
Material	Copper	Rogers 5880	Copper

3. RESULTS AND DISCUSSION

The proposed antenna is simulated by CST microwave software. The simulated reflection coefficient (S_{11}) is plotted in Figure 3. It can be clearly noticed that the reflection value is less than -10 dB at desired frequency, with an excellent bandwidth of 3.5 GHz (58.3 to 61.7 GHz). With maximum value of -10 dB at 58.3 and 61.7 GHz, and minimum value of -18.56 dB at 60 GHz.

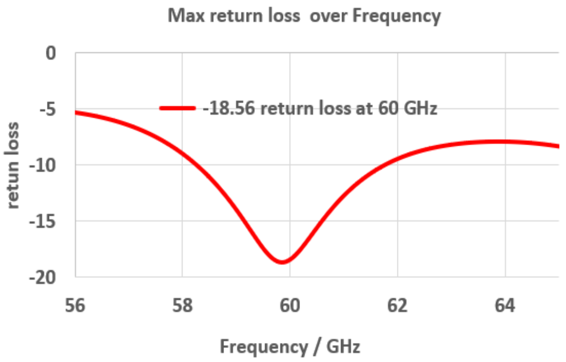


Figure 3. Simulated return loss (S_{11}) of the proposed antenna

The gain of the simulated antenna is shown in Figure 4, over the operated bandwidth of 3.5 GHz. The maximum gain of 7.92 dB is obtained at 60 GHz. The gain values are varying between 7 to 7.98 dB over the frequency range of 58.3-61.7 GHz). In another hand, the simulated antenna achieved a directivity of

8.5 dBi at 60 GHz as shown in Figure 5. The efficiency of the propose antenna can be found in Figure 6. The antenna achieved a high linear efficiency of 91% at 60 GHz. However, the average efficiency along the bandwidth is (3.5 GHz).

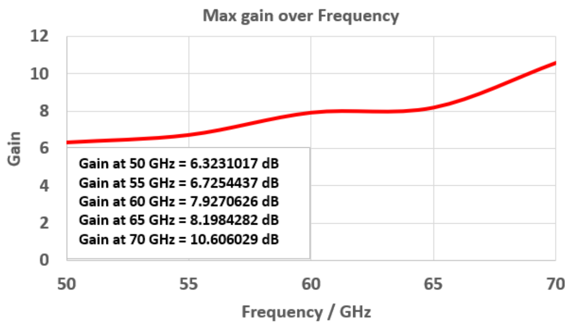


Figure 4. The simulated gain of the proposed antenna

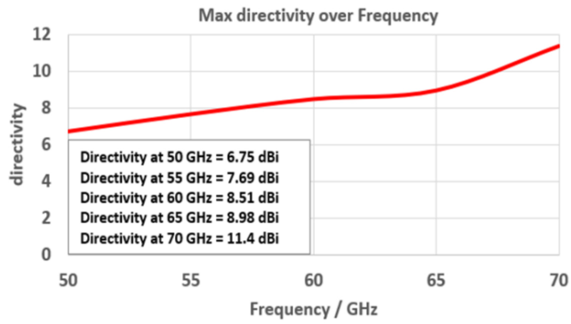


Figure 5. The simulated directivity of the proposed antenna

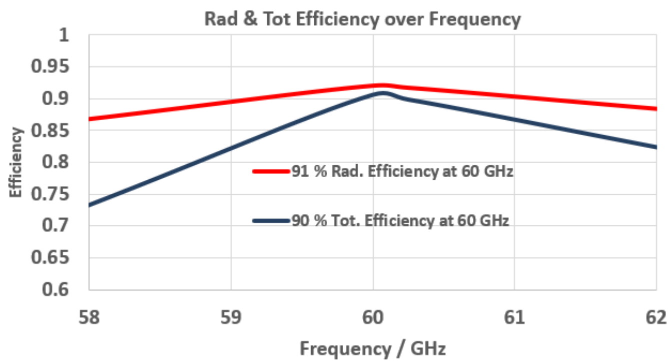


Figure 6. The efficiency of the proposed antenna

The radiation pattern of the proposed antenna at 60 GHz is illustrated in Figure 7. The radiation has a beam width of 25° in the main lobe direction, with side lobes of -5 to -10 dBi. Despite this unwanted side lobes, the main lobe directivity is about 8.51 dBi. Additionally, Figure 8 illustrates the surface current of the suggested 60 GHz antenna. Table 2 summarizes the simulated results of the SIW Minkowski-Sierpinski fractal antenna. Table 3 shows the comparison between the proposed designs with other work.

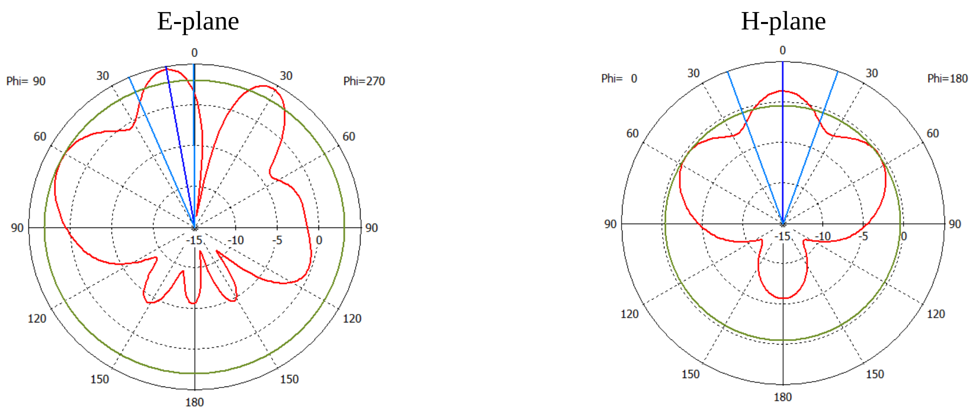


Figure 7. The radiation pattern of the proposed SIW antenna at 60 GHz

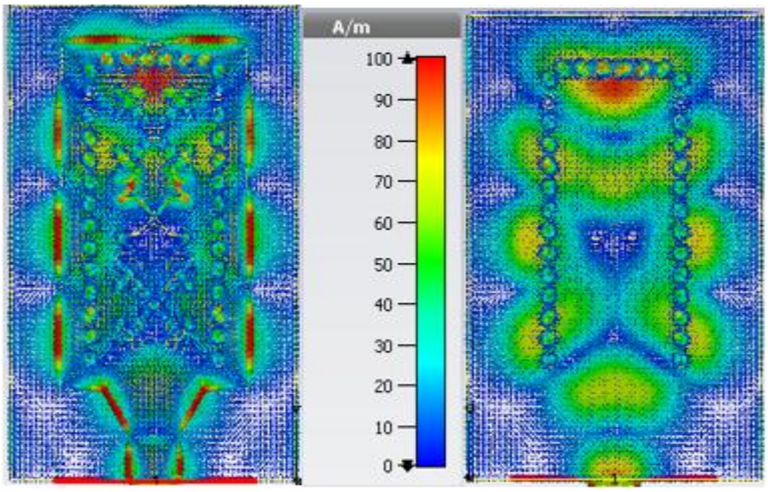


Figure 8. The surface current at 60 GHz

Table 2. The simulated results of the proposed antenna at 60 GHz

Parameter value	Parameter value
Gain	7.9 dB
VSWR	1.27
Reflection coefficient	-18.56 dB
Radiation efficiency	91 %
Transmission Efficiency	90 %
Directivity	8.51 dBi

Table 3. Comparative results of different SIW-born antennas

Ref.	Operating freq. (GHz)	Substrate/dielectric constant	Gain (dB)	B.W (GHz)	Effi. (%)
[29]	60	Rogers 5800	4.57	4	85
[30]	60-79	Rogers 5800	6-6.78	2.25-3.05	86
[31]	60	Rogers 5800	4.45	5	81
This work	60	Rogers 5800	7.9	3.5	91

4. CONCLUSION

This paper presented the design of SIW Minkowski-Sierpinski ground fractal antenna at 60 GHz. A wide bandwidth of 3.5 GHz is obtained. A good return loss of more than -10 dB is achieved at 60 GHz. The antenna has a good directivity of 8.5 dBi and a gain of 7.9 dB. Also, the antenna has excellent linear efficiency between 90-91% over the required bandwidth. The proposed design of this antenna is suitable for WBANs applications. For Future work, the proposed antenna can be designed in the form of array to enhance the efficiency, gain and directivity

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