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ORIGINAL SCIENTIFIC PAPER

An Improved Performance of the Corona-Fractal Textile Antenna Using an Inverse Patch Medium-Defected Ground-Structure Technique

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Abstract. The paper presents the design and analysis of a corona-shaped fractal antenna with a defected ground structure (DGS) for wireless applications. The fractal concept with an inverse patch medium DGS (IPM-DGS) technique is proposed and applied to achieve multi-band frequencies with a high efficiency. The same structure on the top face of the antenna is used as the ground face in an inverse medium. Resulting in the same corona-fractal structure as the DGS. The overall dimension of the antenna is 55mm x 55mm ($0.48\lambda \times 0.48\lambda$ at the lowest resonant frequency) and is designed on a felt substrate to operate at 2.62 GHz, 3.02 GHz, 3.35 GHz, 3.5 GHz, and 3.62 GHz. The maximum gains of 4.06 dBi and 5.13 dBi with efficiencies of 82% and 80 % are observed at 2.62 GHz and 3.02 GHz, respectively, making the proposed antenna potentially suitable for wearable WBAN/WLAN applications.

Keywords: fractal antennas, planar antennas, wearable antennas, defected ground structures, inverse patch medium

Izboljšana zmogljivost koronsko-fraktalne tekstilne antene s tehniko obrabe tal z obrabljenimi srednjimi poškodbami

Ta članek predstavlja zasnovo in analizo fraktalne antene v obliki korone z okvarjeno talno strukturo (DGS) za brezžične aplikacije. Predlagan je in uporabljen fraktalni koncept s tehniko inverznega medija (IPM-DGS) za doseganje večpasovnih frekvenc z visokim izkoristkom. Osnovna ideja je uporaba iste strukture zgornje strani antene na tleh v inverznem mediju. To pomeni, da ima DGS enako korona-fraktalno strukturo. Antena je zasnovana na podlagi iz filca s skupno mero 55 mm x 55 mm ($0{,}48\ \lambda \times 0{,}48\ \lambda$ pri nižji resonančni frekvenci) z uporabo simulacijske programske opreme FEKO. Namenjena antena resonira pri 2,62 GHz, 3,02 GHz, 3,35 GHz, 3,5 GHz in 3,62 GHz. Največji dobiček 4,06 dBi in 5,13 dBi z izkoristkom 82 % oziroma 80 % opazimo pri 2,62 GHz oziroma 3,02 GHz, zaradi česar je predlagana antena ustrezna izbira za nosljive aplikacije.

1 INTRODUCTION

Recently, patch antennas are widely used in wireless communication systems due to their advantages, such as low cost, thin profile configuration, compact size, and ease of fabrication and integration into microwave circuits [1]. They are generally able to work at broadband frequencies through the integration of different broadband techniques. These include the increased thickness of the substrate, defective ground structures of the floor, and modifying the patch structure [2-3]. Moreover, microstrip antennas have a low-impedance bandwidth and low-gain limitations. A single hardware interacts with various wireless standards, including the Wireless Body Area Network (WBAN), the Wireless Local Area Network (WLAN), and 5G (2.3 GHz, 2.6 GHz, and 3.5 GHz).

Recently, wearable antennas are receiving considerable attention due to their cost efficiency, lightweight, flexibility, and easy integration in clothing [4–7]. Usually, textiles or different flexible polymers are the primary materials used. Textiles, on average, lose more energy than standard conductors, lowering the total radiation efficiency. Despite this, the material used to produce wearable antennas remains the most popular as leading textiles can be integrated into clothes directly [8-10].

A fractal is a non-consistent geometric form which is not uniform on all scales [11]. The fractal geometry provides an area-filling feature which improves the antennas efficient electric-path length on a smaller

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surface [12]. Fractal is a repetitive process in which the same form but at different scales is repeated. Hence, various iterations are achieved [13]. Besides using fractal geometries that enable multiband features, a new DGS concept has drawn the attention of many researchers [14]. DGS refers to defects or slots in the planar microwave circuits ground. This emerging technology improves the different parameters of antenna devices, such as narrow bandwidth, cross-polarization, low gain, etc. DGS is one of the several methods that help to suppress mutual coupling effects in microstrip antenna arrays [15].

The paper is organized as follows. Section 2 describes the antenna geometry. Section 3 presents simulation results. Section 4 draws conclusions.

2 Design of THE Fractal Patch/DGS Antenna

The fractal antenna is designed on a felt substrate with a dielectric constant (εr) of 1.3, loss tangent (tanδ) of 0.044 and thickness (h) of 3mm. The substrate size is 55mm x 55mm (0.48λ × 0.48λ). The felt substrate has a Perfect Electric Conductor (PEC) ground on the bottom and a PEC patch on the top. A fractal patch antenna of a corona shape is used. It is fed by a microstrip line of dimensions *Wf* and *Lf*. Figure 1 depicts the antenna structural configuration.

The antenna design follows the self-similarity concept in which the patch is designed by repeating the same shape to obtain the final design. The basic structure of the corona-fractal shape is a circular patch integrated with small elliptical patches at edges. The fractal cells are connected by rectangular patches. The corona fractal has the most simple structure which compared to other geometrical-shaped fractals makes it easier to fabricate. The DGS application includes applying defects (slots) on the ground plane and reduction of an unwanted response. The ground plane is modified by etching the corona-fractal structure to get a slot using the IPM-DGS technique to improve the antenna performance (see Figure. 2). The overall dimensions of the proposed antenna are given in Table 1.

Table 1. Antenna dimensions.

Parameter	Value (mm)
W1	55
W2	3.6
Wf	3.6
L1	55
Lf	17
h	3
R1	9
R2	5.4
R3	3.42

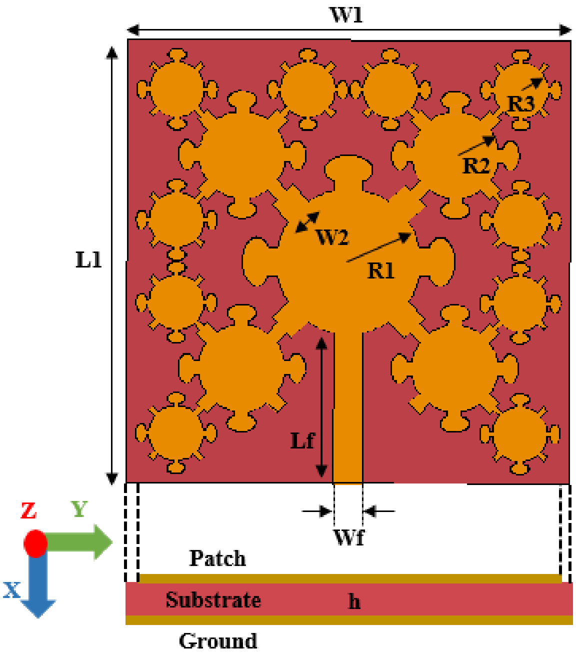

Figure 1. Structure of the corona-fractal antenna design.

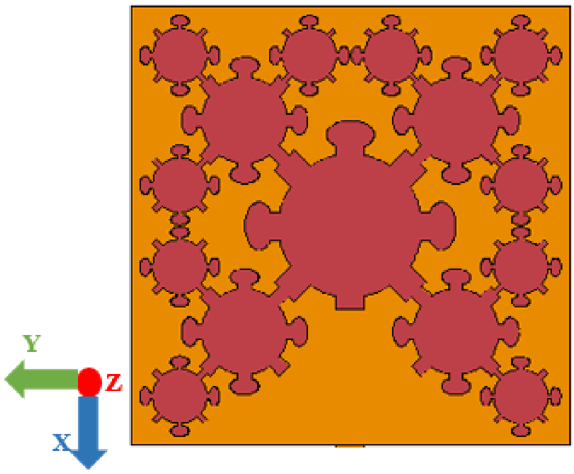

Figure 2. Ground with IPM-DGS.

For linear-equation solutions, the method of moments (MOM) is a numerical approach that can solve many problems, including integral and differential equations, due to its accuracy and effectiveness. Figure 3 shows the surface divided into triangle boundary edges.

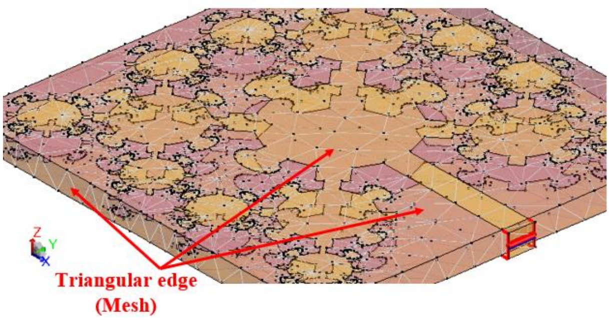

Figure 3. Simulation mesh produced by FEKO.

3 Results and Discussion

The corona-fractal patch antenna with IPM-DGS is simulated and analyzed using the FEKO software. Parameters, such as reflection coefficient, gain, backward radiation, directivity, and 3D radiation pattern, are discussed. A comparison is result between the antenna with the IPM-DGS technique and the antenna without it.

Figure 4 shows the reflection coefficient results antenna. First, a conventional ground plane with no IPM-DGS is used. The single resonant frequency is set to 3.38 GHz with a -25.25 dB reflection coefficient. A ground plane is then modified using the IPM-DGS technique to further improve in the antenna performance. The five resonant frequencies of 2.62 GHz, 3.02 GHz, 3.35 GHz, 3.5 GHz and 3.62 GHz are achieved at minimum reflection coefficients of -20.02 dB, -22.69 dB, -18.84 dB, -13.43 dB, and -25.49 dB, respectively.

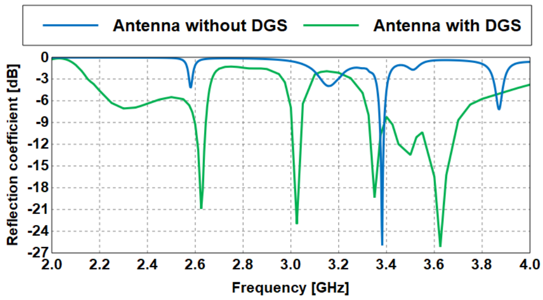

Figure 4. Reflection coefficients of the antenna with and without IPM-DGS.

The next parameter analysed in the paper is the voltage standing wave ratio (VSWR). It is the ratio between the maximum and the minimum voltage along the length of a transmission-line structure. Its value is always greater than 1 (see Figure 5).

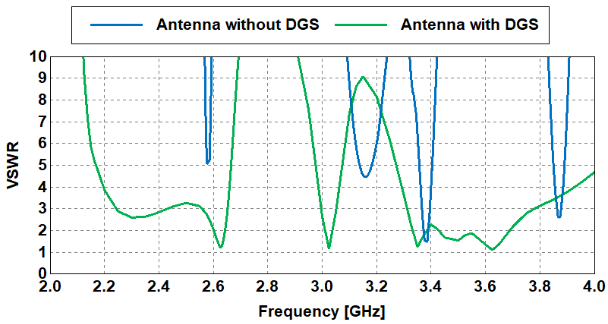

Figure 5. VSWR results obtained with FEKO.

Also, the simulation results show improved antenna impedance matching properties (see Figure 6). Compared to the antenna with no DGS technique, its impedance performance is close to 50.

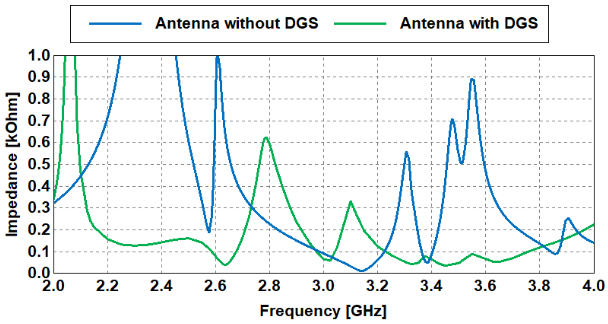

Figure. 6. Impedance matching results.

Moreover, the fractal antenna gain and directivity are significantly improved at $\theta = 0^{o}$. Results in Figure 7 show its gain over a wide range of frequencies. The maximum gain of 5.12 dBi is achieved at 3.02 GHz, and the gain of 4.09 dBi at 2.62 GHz. A directivity value is improved to 6.19 dBi at 3.02 GHz (see Figure 8).

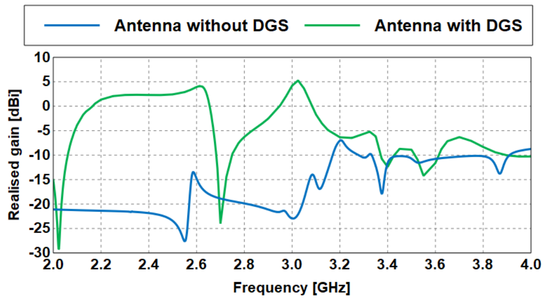

Figure 7. Gain of the antenna with and without IPM-DGS at $\theta = 0^{0}$.

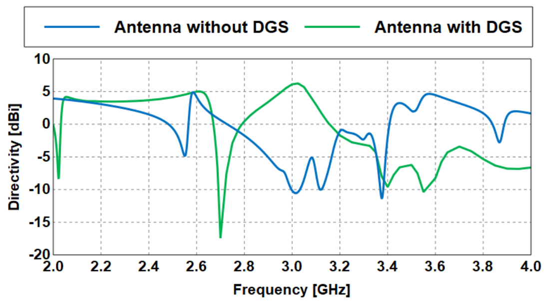

Figure 8. Antenna directivity with and without IPM-DGS at $\theta = 0^{0}$.

Figure. 9 presents the antennas 3D radiation patterns with IPM-DGS. The higher gain of 6 dBi is obtained at 3.02 GHz and the lower gain of 5 dBi at 2.62 GHz and 3.35 GHz, respectively. Also, the gains of 3 dBi and 4 dBi are obtained at 3.5 GHz and 3.62 GHz, respectively.

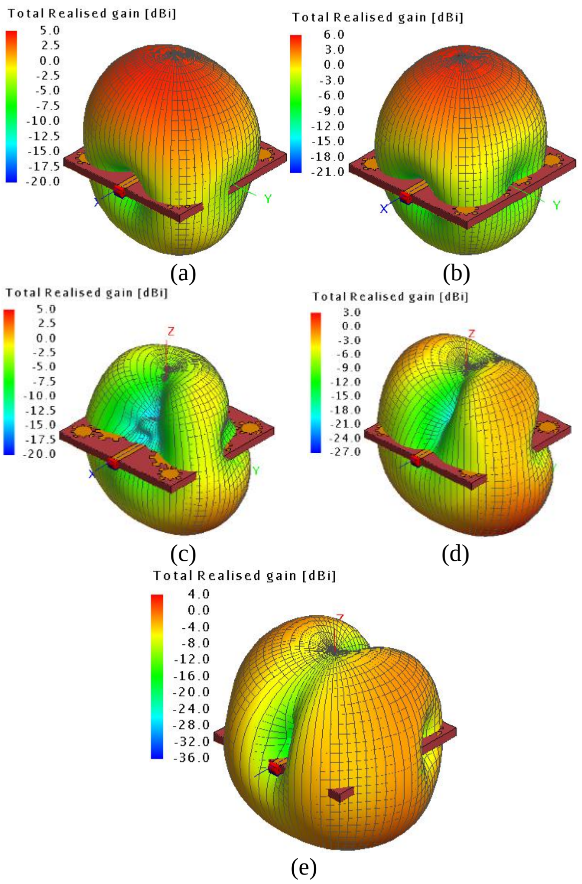

Figure 9. 3D total radiation pattern of the antenna with IPM-DGS at (a) 2.62 GHz, (b) 3.02 GHz, (c) 3.35 GHz, (d) 3.5 GHz and (e) 3.62 GHz.

Also, the antenna integration with IPM-DGS significantly increases its radiation efficiency (see Figure 10).

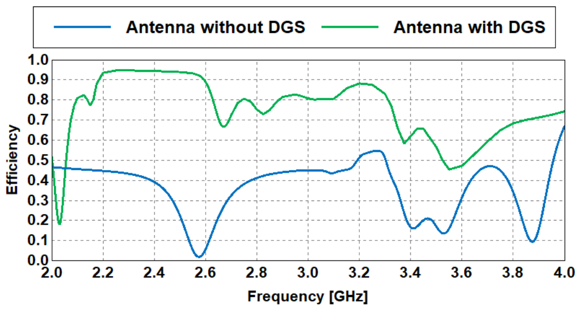

Figure 10. Radiation efficiency of the antennas (with and without IPM-DGS).

Figure 11 shows the surface current distribution at various resonant frequencies. It is relatively weak at 2.62 GHz and 3.02 GHz and is observed at connecting areas between the fractal elements. It then becomes more intense, especially at the resonant frequency of 3.5 GHz (see Figure 11(d)).

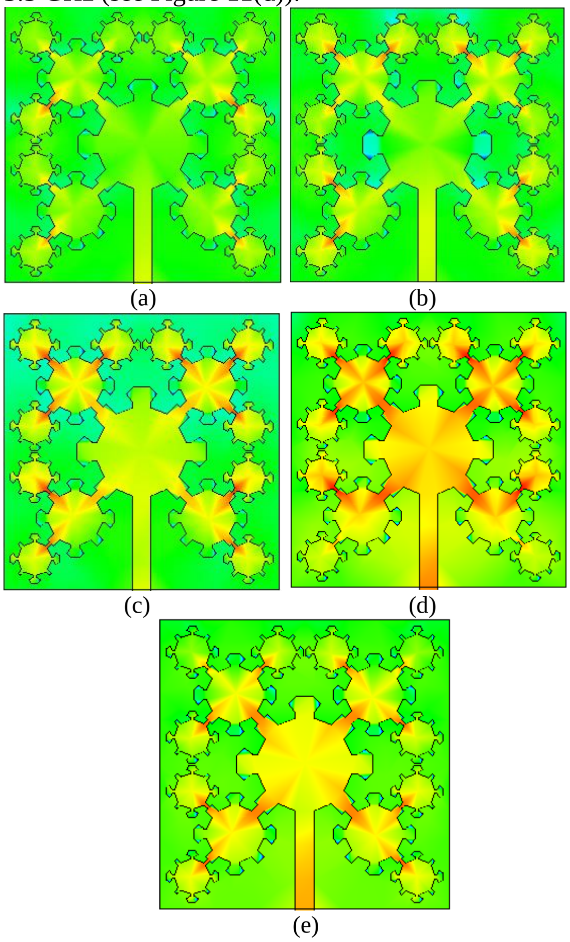

Figure 11. Surface current distribution of the antenna with IPM-DGS at (a) 2.62 GHz, (b) 3.02 GHz, (c) 3.35 GHz, (d) 3.5 GHz and (e) 3.62 GHz.

Table 2 shows the simulation results.

Table 2. Antenna simulation results.

Resonant frequency (GHz)	Reflection coefficient (dB)	Gain (dB)	Directivity (dB)	Efficiency (%)
2.62	-20.02	4.03	4.94	83
3.02	-22.69	5.14	6.22	80
3.35	-18.84	-6.16	-4.29	86
3.5	-13.43	-9.05	-6.32	56
3.62	-25.49	-9.34	-6.27	50

4 Conclusion

A new Corona-fractal antenna based on the IPM-DGS technique is designed and simulated. Comparison between the proposed antenna and a version with the DGS replaced by a full ground plane. The antenna with the full ground plane resonated only at 3.38 GHz, and the antenna integrated with IPM-DGS resonated for five resonant frequencies 2.62 GHz, 3.02 GHz, 3.35 GHz, 3.5 GHz, and 3.62 GHz. The proposed antenna with the DGS exhibited a radiation efficiency of up to 82 % at 2.62 GHz. Gain is improved over a wide range of frequencies, with a maximum of 4.06 dBi and 5.13 dBi is achieved at 2.62 GHz and 3.02 GHz, respectively. The performance of the proposed antenna is improved compared to other fractal antennas, and can be potentially used in various WBAN and WLAN applications.

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