DEVELOPMENT OF KOCH SNOWFLAKE FRACTAL TYPE ANTENNA WITH DGS FOR SMART TEXTILE APPLICATIONS

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ARTICLE INFO

Article history:
Received:
Accepted:
Online:

Keywords:
SIGW
Smart textile
Wearable electronics
Fractal antenna
Koch Snowflake

ABSTRACT

This work proposes a new textile-based multiband Koch Snowflake shape fractal antenna with concave hexagonal shape twin slots. It is optimized for the GSM, Wi-Fi, X and Ku frequency bands for smart textile-based applications. The size of the antenna is 86.4*60mm2. The conductor layer (copper tape) has thickness of 0.035mm. Four textile fabrics are considered as substrates, namely, Felt (εr=1.22), Cotton (εr=1.8), Leather (εr=2.95) and Polyester (εr=1.9) with a thickness of 2mm. The Finite Difference Time Domain (FDTD) method (CST Microwave Studio) is used design and simulate the antenna. The largest bandwidths are achieved on the Felt, -10dB reflection coefficient bandwidths are 2.6 GHz, 1.55 GHz and 3.7 GHz, with radiation efficiencies of about 92%. The flexibility offered by textiles is examined by weaving the four different fabrics into one substrate which showed the enhancements in the antenna gain and bandwidth at higher frequencies. It is shown that, this antenna is a promising design for smart textile applications.

1. Introduction

Recent developments in wearable electronics and smart textiles lead this technology to be used in different industries such as military, heath monitoring, sensor or actuator and energy harvesting [1-2]. The development of small devices capable of transmitting and receiving data at low power with the highest possible data rates and multi- or wide- bandwidths is required by new applications in the field of smart textile systems [3]. On the same side, shifting carrier frequencies to multi-bands resonances is an important requirement for meeting the long-term needs of the next generations of smart textile based systems. Antennas are the crucial part of any systems and requires to fit some design requirements. Despite their advantages of being low cost, small size, lightweight simple to develope and to integrate with other circuit components, patch antennas have a limited bandwidths. For this reason, fractal shapes are suggested to be integrated into the design of traditional antennas as a technique to increase their bandwidths. With unique characteristics linked to their geometeries, all fractal units have common properties, and their propeteries can be generated and adjusted by resizing the geometrical structure either by adding or subtracting the fractal elements. One of the common types is the Koch fractal. When compared with conventional antennas, their sizes are smaller with great enhancements in the bandwidth and radiation efficiency [4].

The main contributions of this study are as follow: (1) evelop a textile based wide band compact rosonating antenna at the GSM, LTE, and Wi-Fi frequency bands, (2) optimize the antenna geometry comprises two identical slots shape of concave hexagonal shape, (3) study the antenna performance on different textiles and on a substarate made of combined fabrics.

2. Antenna structure and Design process

A. *KOCH SNOWFLAKE STRUCTURE*

The Koch Snowflake structure can be first formed with a L-length equilateral triangle. Each side of the triangle is then divided into three equal lengths for the first iteration. Each side's mid-length is then removed, and another equilateral triangle is constructed in its place. Each of the latest triangular protrusion's sides is 1/3 the original length of the side. This process is repeated until the optimum iteration number is found. As shown in [5], the lengths of the iterated sides are governed by the following Equation (1):

$$L_k = L(\frac{4}{3})^k \tag{1}$$

where k is the segment number and L_k is the new length after the iteration. As a result of the iterations, to increase the iteration, one can divide each side into three equal parts and replace the middle part with a triangle with a length equals to 1/3 of the orginal length. Since the increase in the iterations causes increments in the Euclidean length, while the the width remains constant. Consequently, the surface current distribution increases and as a result an improvement in the overall gain can be obtained. Figure 1 demonstrates the different iterations used for the current design.

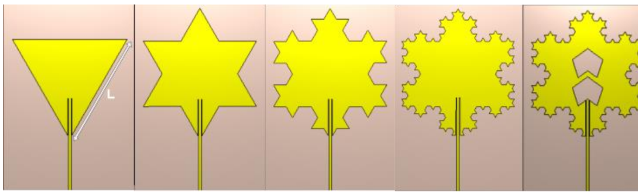

Figure 1. Iterations of the design procedure

B. ANTENNA PARAMETERS

The optimized surface area of the antenna is 86.4 mm*60 mm, with a Felt (ε_r=1.22) substrate, thickness of 2 mm and loss tangent of 0.02. Both the patch and ground layers conductors are made of copper with thicknesses of 0.035 mm. The twin, concave shape hexagonal patches are selected, optimized and applied to the antenna to add a new and unique identity to the structure as shown in Figure 2. The slots are kept small to prevent interfering with the flow of the surface current. The optimized parameters are listed in Table I.

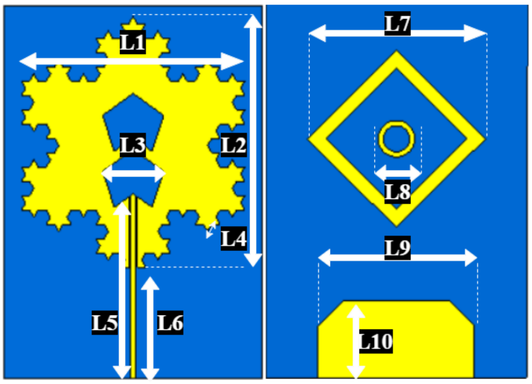

Figure 2. Front patch side (left) and back side (right) of the antenna

TABLE I. PARAMETERS VALUES OF THE PROPOSED ANTENNA

Parameters	***L1***	***L2***	***L3***	***L4***	***L5***
Value (mm)	51.84	59.9	14.17	1.92	42.37
Parameters	***L6***	***L7***	***L8***	***L9***	***L10***
Value (mm)	25.7	40.8	8.4	36	15

C. *Defected Ground Structure (DGS)*

The DGS is a technique of engraving different geometries on the ground plane to enhance the antennas or filters performances and their bandwidths. It directly changes the surface current distribution and as a result, the antenna characteristics in term of resonance frequencies, impedance, and efficiency change because of the generation of parallel-tuned circuit [5]. These ground structures can be either periodic or non-periodic in geometry [6].

In the current design, the ground structure consists of two geometries, namely, a rhombus shape enclosing a circle and beveled rectangle. The position of the rhombus shape is precisely optimized and placed at the center of the antenna's back. The rhoumbus and the circle shapes are used in regions with the densest surface current flow, consequently to further enhance the bandwidth. A noticeable enhancement of the bandwidth is clearly achieved as will be shown later in section 3. The cut edges are optimized in this way to achive a widest bandwidth [7].

3. PARAMETRIC STUDIES AND RESULTS

In this part of the study, the antenna behavior is simulated on different textile fabrics in terms of permittivity changes of the substrate. The effect of the DGS and its geometry changes, and finally the effect of combining (weaving) all four fabrics with different permitivites as on layer are also studied.

A. *ANTENNA PERFORMANCE ON DIFFERENT TEXTILE FABRICS*

The antenna behaviour in terms of the reflection coefficients, gains (G) and radiation efficiency (η_e) on different substrates is examined for four commonly used textile materials. The chosen textiles are Felt (ε_r=1.22; tan δ = 0.016), Cotton (ε_r=1.8; tan δ =0.06), Leather (ε_r=2.95; tan δ = 0.006) and Polyester (ε_r=1.9; tan δ = 0.0045), all with a fixed thickness of 2 mm. The simulated S_{11} results of the proposed structure show that, multiband wide and ultra-wide resonances are achieved on Felt, Cotton and Polyester substrates. As illustrated in Figure 3, the antenna resonates around three bands (triple band). The widest band width is obtained on the Felt substrate, the obtained -10 dB reflection coefficient resonance frequencies are in the ranges of 1.5 - 4.1 GHz, 8 - 9.55 GHz and 12.6 - 16.3 GHz, which meet the requirements of the GSM, LTE, and WiFi applications. The detailed antenna gains and radiation efficiencies are further presented in tables II. The overall optimized dimensions of the antenna on Felt is 86.4 mm *60 mm with a substrate thickness of 2 mm.

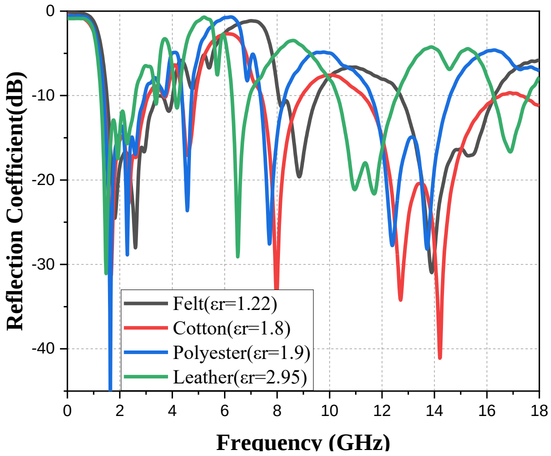

Figure 3. Reflection coefficients for the four different fabrics

B. THE DGS EFFECT

The defected structures on the ground plane affect the characteristics of the antenna and impact the surface current distribution. As shown in Fig. 4, the optimized antenna on Felt substrate without DGS resonates around 2.2 GHz, 4.2 GHz and 14 GHz with very narrow band widths. On the other hand, bandwidth enhancements by factors of about 10 and 6 in the 2.2 GHz, 4.2 GHz bands are obtained with the use of DGS. In addition, a new resonance wideband appears around 9 GHz with a bandwidth of about 1.8 GHz.

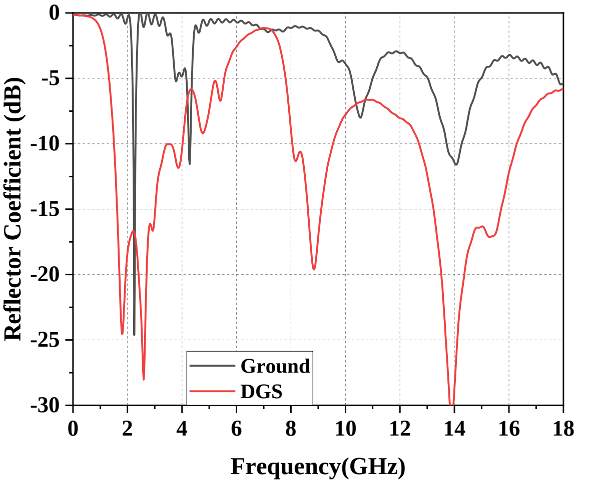

Figure 4. Reflection coefficients of the antenna with normal ground (black) and with DGS (red) on the Felt substrate

In order to demonstrate the effects of the geometrical paramaters of the DGS on the output gain and bandwidth of the antenna, we select one parameter, namely L_{10} and vary its values between 11 mm to 21 mm with step size of two. This parameter is chosen because of its great influence on the obtained results. As shown in Figure 5, the first and third resonance bands disappear for L_{10} values above 15 mm, while the second band shifts twards higher frequencies for L_{10} = 15, 17, 19, and 21, respectively. The obtained results show that the optimum value with respect to the targeted bandwidths and return losses is L_{10} = 15 mm.

TABLE II. GAINS AND RADIATION EFFICIENCIES VALUES FOR THE DIFFERENT FABRICS

Material type	G (dB) 1.8 GHz	G (dB) 2.4 GHz	G (dB) 8 GHz	G (dB) 12 GHz
FELT	2.77	3.76	7.21	6.26
COTTON	2.92	3.70	4.32	6.42
POLYESTER	2.89	3.08	4.63	7.06
LEATHER	2.95	3.81	NA	5.90
Material type	η_e	η_e	η_e	η_e
FELT	92%	87%	67%	72%
COTTON	85%	70%	60%	50%
POLYESTER	95%	80%	90%	89%
LEATHER	93%	91%	NA	83%

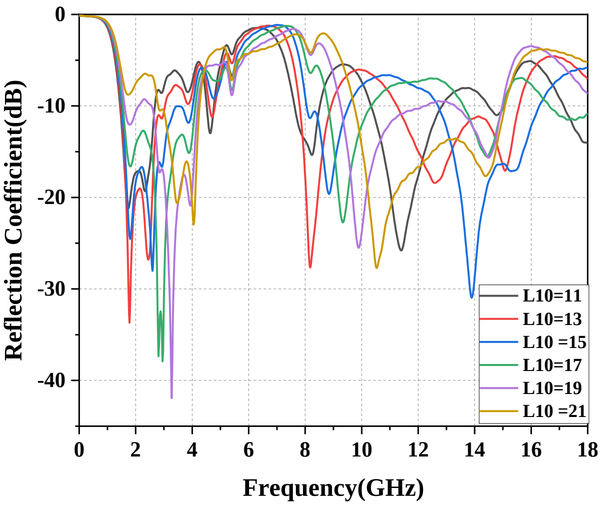

Figure 5. Reflection coefficients of different values of L10 of the rectangular DGS on the ground plane

C. COMBINED FABRICS

In this part, we examine the flexibility offered by textiles in designing new structures. We combined the four different textile materials in different scenarios as shown in Fig. 6. Four different arrangements based on the values of dielectric constants are implemented by changing the positions of the fabrics. The S_{11} results show an enhancement in the obtained bandwidth of the antenna by about 1 GHz compared to the case with only Felt as a substrate. The resonance frequency ranges are 1.4 - 3.69 GHz, 4.38 - 4.8 GHz, 7.74 - 9.4 GHz and 11.8 - 16.3 GHz at the first scenario.

As shown in tables III, the performance of the antenna in terms of its gain and radiation efficiency at 1.8 GHz is not sensitive to the relative placements of the fabrics, while, some enhancements are noticed at higher frequencies.

Good enhancements in the antenna bandwidth, radiation efficiency and gain are observed in the third scenario.

Fig. 7 depicts the –10 dB reflection coefficent behaviour of the four scenarios, an enhancement in bandwidth by about 1 GHz is obtained in comparsion to the case with only Felt as a substrate. Moreover, a full comparison between all individual substrates and the different mix scenarios in terms of the fractional bandwidth is listed in table VI.

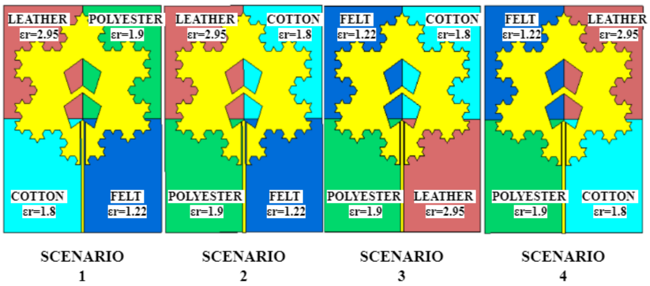

Figure 6. Different scenarios considered in the current study.

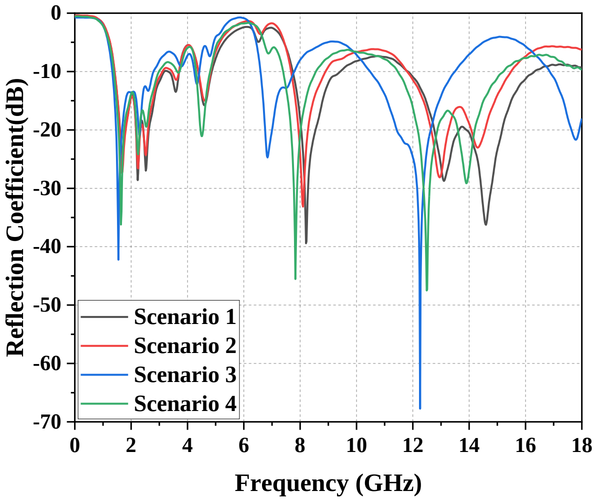

Figure 7. Reflection coefficients of the different scenarios

TABLE III. GAINS AND DIFFERENT RADIATION EFFICIENCIES FOR DIFFERENT SCENARIOS

Material type	G (dB) 1.8 GHz	G (dB) 2.4 GHz	G (dB) 8 GHz	G (dB) 12 GHz
SCENARIO 1	2.29	3.50	3.75	5.54
SCENARIO 2	2.58	3.47	4.13	6.94
SCENARIO 3	2.39	2.65	4.75	7.38
SCENARIO 4	2.53	3.08	3.45	6.22
Material type	η_e	η_e	η_e	η_e
SCENARIO 1	89%	87%	67%	65%
SCENARIO 2	91%	90%	86%	85%
SCENARIO 3	91%	75%	87%	82%
SCENARIO 4	90%	85%	75%	68%

TABLE IV. FRACTIONAL BANDWIDTHS OF DIFFERENT FABRICS AND COMBINED STRUCTURES

MATERIAL TYPE	L and S-Band	C-Band	X- Band	Ku-Band
FELT	108.3%	NA	19.40%	30.80%
COTTON	70.80%	NA	20.00%	35.84%
POLYESTER	63.34%	7.23%	11.87%	25.00%
LEATHER	50.00%	NA	9.13%	19.00%
SCENARIO 1	95.42%	8.94%	20.75%	37.50%
SCENARIO 2	76.67%	8.94%	14.50%	30.84%
SCENARIO 3	59.58%	NA	15.37%	24.59%
SCENARIO 4	67.50%	10.63%	14.38%	30.42%

The radiation patterns of the proposed antenna in E-plane are presented in Figure 8 for the Felt substrate and for the four frequencies, 1.8 GHz and 2.4 GHz, 8 GHz, and 12 GHz.

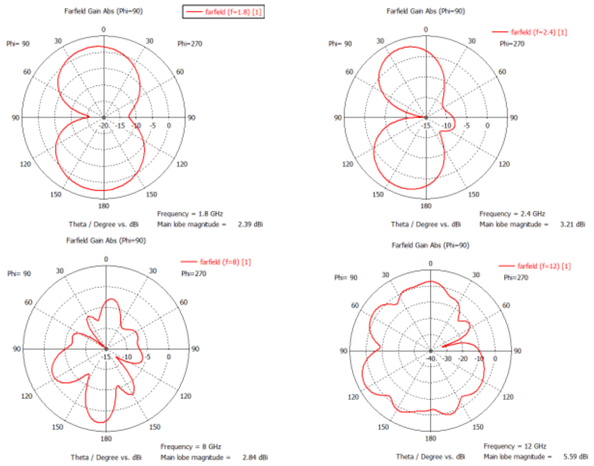

Figure 8. Radiation patterens for the Felt antenna

IV. Conclusıon

In this study, a multiband Koch Snowflake patch antenna with concave hexagonal slots and with DGS is developed on textile-based substrates. The obtained results show that the Felt substrate demonstrates the best performance in terms of return losses, bandwidth, and gain. Combining the fabrics of different substrates in one layer enhances the results and expands the bandwidth. The obtained bandwidth with Felt as a substrate is 7.85 GHz, for leather material the bandwidth is 4.21 GHz, for the cotton fabric it is 7.6 GHz and for polyester is 5.81 GHz. Combining all fabrics as one substrate enhances the bandwidth by a factor of 1.12.

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