Journal of Physical Sciences, Vol. 18, 2014, 7-13
ISSN: 0972-8791, www.vidyasagar.ac.in/journal
Published on 27th March 2014

Use of Minkowski Fractal Geometry for the Design of Wearable Fully Fabric Compact Antenna

S. Sankaralingam[a], S. Dhar[a], A. K. Bag[b], A. Kundu[a] and B. Gupta[a]

[a]Jadavpur University, Kolkata, India - 700032
[b]Bengal Institute of Technology and Management, Santiniketan, India – 731236
Email: slingam.nec@gmail.com

Received on 1th March 2014; accepted on 25th March 2014

ABSTRACT
This paper describes the use of Minkowski fractal geometries for the design of wearable electro-textile or fully-fabric antenna. Two electro-textile materials namely Flectron and Shieldit are considered for the design of flexible microstrip antenna. Flectron and Shieldit fabric materials are used for ground plane and patch of the antenna respectively. In this design, polyester fabric material has been employed as dielectric medium. In the basic design, the antenna is designed for WLAN applications. The designed Shieldit antenna provides a gain of 5.9 dB with an impedance bandwidth of 130 MHz. By applying Minkowski fractal geometry to the antenna, miniaturization or compactness is achieved. In its first iteration, antenna design is optimized and tuned to WiBro band and in the second iteration, antenna is further miniaturized in order to make it suitable for GSM 1900 applications. In these two bands, the gain and efficiency of the Shieldit antenna conform to their respective wireless standards.

Keywords: Fabric Material, Minkowski Fractal Geometry, Wearable Antenna

1. Introduction

Development of wearable microstrip antennas has rapidly increased in the recent years, as microstrip configuration is conformable to any shape. Antenna properties such as compact size, easy fabrication, mechanical flexibility, comfort to the user and low cost are essential requirements to design antennas for wearable applications. The concept of developing compact antennas by applying miniaturization technique using fractal geometry was proposed in 2002 [1]. A wearable dual-band Sierpinski fractal PIFA using Shieldit conductive fabric has been proposed in 2011 [2]. The performance of Giuseppe Peano fractal geometry as compared to usual fractals such as Koch and Sierpinski has been demonstrated for miniaturization of microstrip antennas employing copper and FR4 substrates in [3]. M. E. Jalil et. al. have proposed a triple band fractal Koch dipole antenna made of copper tape and denim textile material suitable for wearable applications in [4]. Recently, a CPW slot loop fed Minkowski fractal dielectric resonator antenna has been proposed in [5].

In light of the abovementioned discussion, a compact Minkowski island fractal shaped electro-textile antenna employing potential conductive fabrics such as Flectron and Shieldit with polyester fabric as dielectric material has been designed for WiBro and GSM 1900 applications. This paper is organized as follows: Section II describes the properties of Minokowski island fractal and its iterative-generation procedure. Steps involved in the antenna design are discussed in Section III. The performance characteristics of the designed antenna are listed in Section IV. Concluding remarks are drawn in Section V.

2. Brief background on Minkowski fractal geometries

An important property of any fractal geometry is the possibility of obtaining an arbitrarily long curve confined in a given space. This property can be exploited effectively in the process of antenna miniaturization. Another interesting property of fractal geometry is the self-similarity property. Self similarity can be described as the replication of the geometry of the structure at a different scale within the same structure. Self similarity property of fractals may result in multiband behavior of the fractal shaped antennas. The iterative-generation procedure for a Minkowski island fractal is depicted in figure 1.

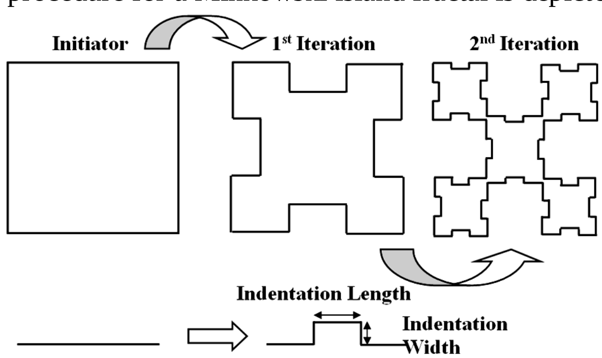

Figure 1: Iterative generation Procedure for a Minkowski Fractal

The fractal is formed by displacing the middle one-third of each straight segment (indentation length) by some fraction called the indentation width. Indentation factor (i) is defined here as the ratio of indentation width to the indentation length. The resulting structure has five segments for every one of the previous iteration, but not all of the same scale. Changing the indentation factor causes a shift in the resonant frequencies, so proper tuning of the indentation factor is necessary to obtain the frequencies required for WiBro and GSM 1900 applications.

3. Antenna Design Procedure and Modeling

To start with, rectangular shaped wearable antenna is designed with the specifications given in Table 1 using CST Microwave Studio 2010. The antenna is fed through an aperture using microstrip line. Width of the microstrip line is calculated for 50 ohm characteristic impedance and its length beyond the aperture is optimized to achieve best impedance matching. Size of the ground plane and the substrate is taken as 120 mm X 120 mm. The patch layer and the ground plane of the antenna are made up of conductive fabrics having thicknesses of 0.1125 mm (Shieldit) and 0.1524 mm (Flectron) respectively. The patch dimensions for each of the antenna are optimized to get a resonance frequency of 2.45 GHz. This constitutes the basic design for zeroth iteration of the fractal geometry for the antenna under consideration and to be used for WLAN applications.

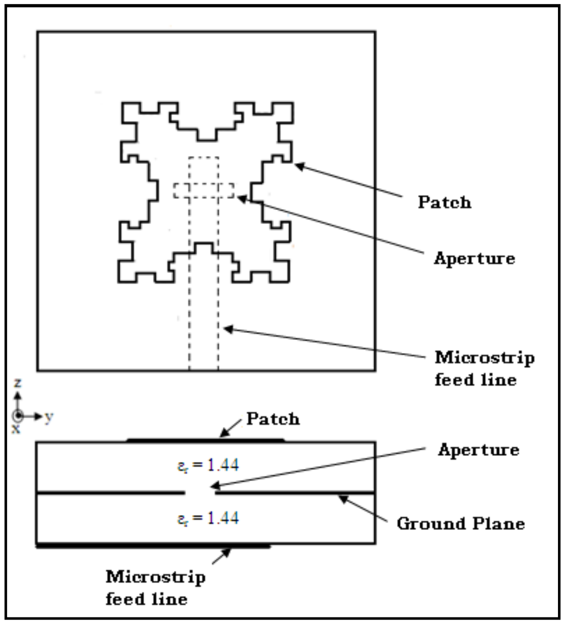

Figure 2: Geometry of the antenna with 2nd iteration

By applying Minkowski fractal geometry to this basic antenna, miniaturization is achieved. In its first iteration, antenna design is optimized and tuned to WiBro band and in the second iteration; antenna is further miniaturized in order to make it suitable for GSM 1900 applications. Geometry of the antenna with 2nd iteration is depicted in figure 2

TABLE I: DESIGN SPECIFICATIONS OF ANTENNA

Design parameter	Value
Resonant frequency (GHz)	2.45
Substrate dielectric constant	1.44
Substrate thickness (mm)	2.85
Loss tangent of the substrate	0.01
Material used for ground plane	Flectron
Material used for patch	Shieldit
Insulating fabric material employed	Polyester

4. Performance Characteristics

A. Impedance Characteristics:

Simulations are carried out over the frequency range of 1.0 GHz to 4.0 GHz with a frequency step size of 3 MHz for the Shieldit antenna which is under investigation. Fig. 3 shows the simulated S11 plots for the Shieldit antenna with zeroth, 1st and 2nd iterations of the Minkowski fractal geometry. As depicted by the simulation results, this wearable antenna resonates at a frequency of 2.44 GHz, 2.29 GHz and 1.93 GHz for zeroth, 1st and 2nd iterations respectively. Corresponding -10dB return loss bandwidths are 130 MHz, 100 MHz and 63 MHz respectively. This implies that antenna resonant frequency has been reduced considerably in each successive iteration without changing the overall antenna dimensions and thereby miniaturization is achieved.

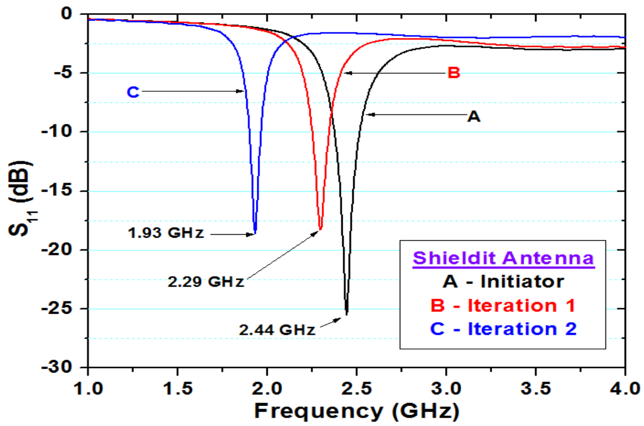

Figure 3: Return Loss characteristcs of Shieldit antenna

B. Radiation Characteristics:

The total far-field radiation patterns of the Shieldit antenna for each of iterations are obtained at the corresponding simulated resonant frequencies. These simulated total far-field patterns for all three versions of the Shieldit antenna at the corresponding resonant frequencies are shown in fig. 4.

Simulations are done for a range of frequencies from 1.0 GHz to 4.0 GHz and the antenna parameters like gain, directivity, beamwidth in principal planes and radiation efficiency are tabulated in Table 2. Gain and radiation efficiency plots for all three versions of the Shieldit antenna are shown in figure 5. This antenna yields a gain of 5.9 dB in the zeroth iteration and 5.0 dB and 1.65 dB in the 1st and 2nd iterations respectively. Corresponding radiation efficiencies in these three iterations are 55.33 %, 40.55 % and 25.70 % respectively. Directivity values for the Shieldit antenna in the zeroth, 1st and 2nd iterations are 8.4 dBi, 8.2 dBi and 7.59 dBi respectively.

TABLE 2: IMPEDANCE AND RADIATION CHARACTERISTICS OF SHIELDIT ANTENNA

Parameter	**Iteration No.**		
	0^{th}	**1^{st}**	**2^{nd}**
Resonant Freq. (GHz)	2.44	2.29	1.93
Imp. Bandwidth (MHz)	130	100	63
Gain (dB)	5.9	5.0	1.65
Directivity (dBi)	8.4	8.2	7.59
3 dB beamwidth (E)	73^0	75.7^0	78.1^0
3 dB beamwidth (H)	61.8^0	62.5^0	67.5^0
Efficiency (%)	55.33	40.55	25.7

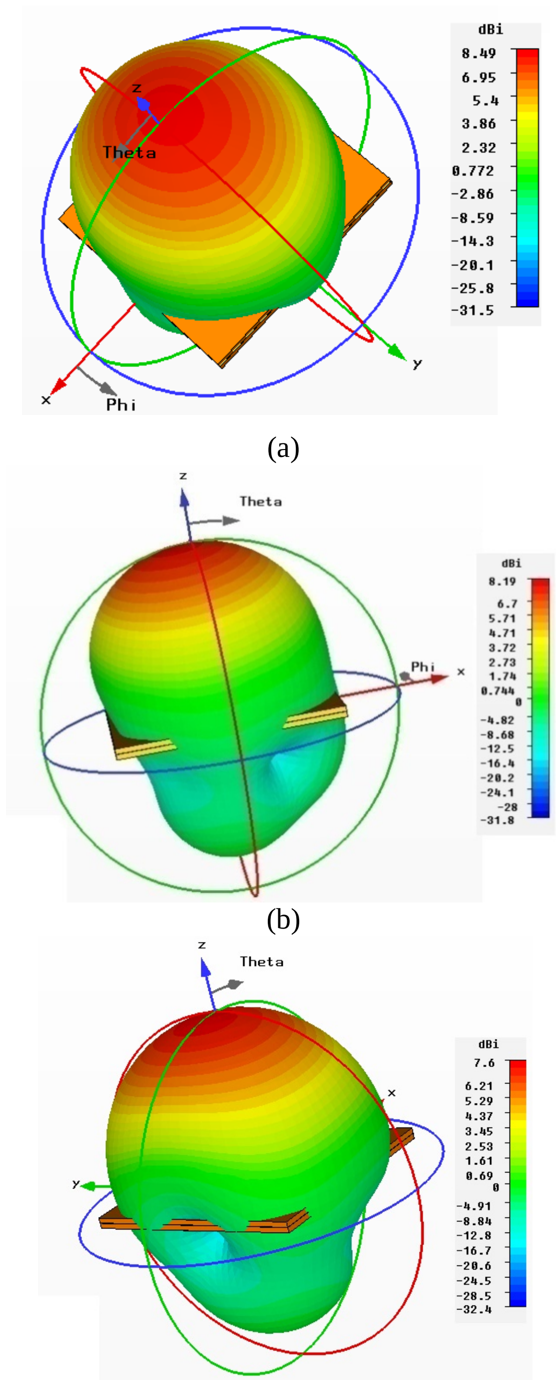

Figure 4: Total radiation pattern of Shieldit antenna for (a) zeroth (b) 1st and (c) 2nd iterations

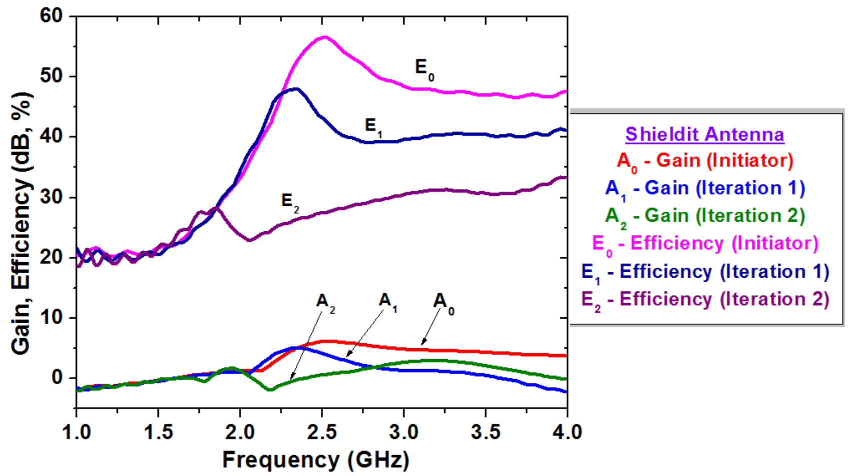

Figure 5: Gain and Efficiency vs Frequency for the Shieldit antenna

4. Conclusion

In this study, miniaturization of wearable electro-textile antennas is achieved by the use of Minkowski fractal geometries of the 1st and 2nd iterations. Two electro-textile materials namely Flectron and Shieldit fabrics have been employed for the design of Minkowski fractal shaped wearable antenna. In the zeroth iteration, the antenna dimensions are chosen to suit for WLAN applications. In the 1st and 2nd iterations the fractal geometry parameters are tuned for optimal performance in the WiBro and GSM 1900 bands respectively with achievement of compactness as an additional feature. In all the three frequency bands, the designed antenna gives good performance characteristics. Experimental verification of these simulation results are in progress and the authors would like to present those measurement data in their next paper.

Acknowledgement: This research work is being supported by a project under the UPE (Phase II) scheme sanctioned by University Grants Commission, New Delhi vide sanction order D.O. No. F. 14-2/2008 (NS/PE)/ dated 01.12.2011.

REFERENCES

1. John P. Gianvittorio and Yahya Rahmat-Samii, Fractal Antennas: A Novel Antenna Miniaturization Technique and Application, IEEE Antennas and Propagation Magazine, 44(2004) 20-36.
2. P.J. Soh, G.A.E. Vandenbosch, S.L. Ooi, M.R.N. Husna, Wearable dual-band Sierpinski fractal PIFA using conductive fabric, Electronics Letters, 47(2011) 1-2.
3. Homayoon Oraizi and Shahram Hedayati, Miniaturization of Microstrip Antennas by the Novel Application of the Giuseppe Peano Fractal Geometries, IEEE Transactions on Antennas and Propagation, 60(2012) 3559-3567.
4. M.E. Jalil, M.K.A. Rahim, N.A. Samsuri and N.A. Murad, Triple Band Fractal Koch Antenna for Wearable Application, Proc. of Progress in Electromagnetics Reasearch Symposium, KL, Malaysia, 1285-1289 (2012).

5. S. Dhar, R. Ghatak, B. Gupta and D. R. Poddar, A Wideband Minkowski Fractal Dielectric Resonator Antenna, IEEE Transactions on Antennas and Propagation, 61 (2895-2903) 2013.