Design of a Compact antenna for Biomedical Applications

Tanmaya Kumar Das
Department of Electronics and Communication Engg.
National Institute of Technology
Rourkela, India
tanmaykumar.das@gmail.com

Santanu Kumar Behera
Department of Electronics and Communication Engg.
National Institute of Technology
Rourkela, India
skbehera@ieee.org

***Abstract*—A compact microstrip antenna with a rotated corrugated slot having Koch fractal geometry is presented in this paper. The antenna is having an operational bandwidth from 1.72 GHz - 2.57 GHz. The low frequency enables the high penetration into the human body. It shows 39.53% of fractional bandwidth centered at 2.15 GHz with a peak gain of 3.1 dB over the band. The antenna has front-to-back ratio around 3.19-5 dB and efficiency more than 94%. The dimension of the antenna is $0.14 \times 0.29 \times 0.07\ \lambda^3$, where λ represents the wavelength of smallest frequency in the required band of operation. This antenna can be suitable for biomedical applications.**

Keywords*—*Microstrip antenna; Koch fractal; biomedical; corrugated slot; folded ground plane.

I. Introduction

In recent years microwave imaging is one of the promising techniques employed to design diagnostic systems. The low-cost, small size, non-ionizing properties makes the method attractive in medical applications. It can be utilized for detection of brain tumor [1], heart failure [2], brain stroke [3], and breast cancer [4]. The prime objective in any microwave imaging system is to analyze the scattered signal from tumorous tissues for detection of diseases. This phenomenon occurs by the variation of dielectric constant between malignant and healthy tissues [3]-[4].

In case of brain tumor detection, the basic criteria are to find out malignancies inside the brain. Antenna is one of the important components in brain imaging system. Low frequency operational band of the antenna is very much essential in order to have reasonable penetration of signal into human head [1], [5]. The desired quality of the antenna is to improve the reflected signal from the malignant tissues. Therefore, efficient system depends on performance of antenna in terms of radiation characterization and reception of the signal. In order to obtain low operating frequency band of interest, different types of antennas have been proposed [1]-[3], [5]-[10].

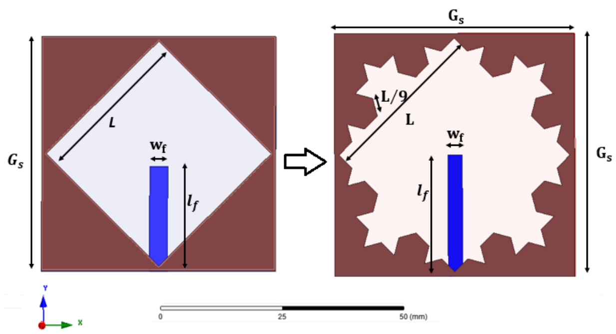
In this paper a new technique using 3D compact antenna is proposed. Here a structure with rotated slot is used to have a wide operating bandwidth. The low frequency requirement of the antenna is fulfilled by the corrugated fractal structure. Koch curve fractal is used to design the slot on the ground plane. As a result of which, it enhances the current path without changing the dimension of the antenna. Overall size of the antenna is reduced with the help of folding technique. Parasitic patches are added in the structure at center of the slot and at bottom of the structure in order to compensate the effect of folding on the input impedance. The proposed design achieves an operating bandwidth of 1.72-2.57 GHz which satisfies the low frequency requirement. The antenna can be used for biomedical applications. Antenna geometry and design of the proposed structure are presented in section II. Simulated results are shown in section III followed by the conclusion in section IV.

II. Antenna Design

Geometry of the initial design of the structure (without folding) is shown in Fig. 1. The antenna is constructed on a square FR4 substrate of length (G_s) having a relative permittivity (ε_r) = 4.4 and thickness (h_s) = 1.6 mm with a square slot of length, L ground plane. Development of the proposed structure begins with the form as shown in Fig. 1(a), and gradually the outer borders in the slot is designed with the help of Koch curve fractal at 2nd order iteration (Fig. 1(b)). The length of the fractal can be calculated by using following formula [10]:

$$l_n^{Koch} = a.\left(\frac{4}{3}\right)^n \quad (1)$$

where 'n' is iteration order of the Koch curve and 'a' is length of the initial segment. Fractal shape of the slot with proper iteration order is incorporated, for further enhancement in bandwidth of the antenna.



(a) (b)

Fig.1. Antenna geometry (Rear view) (a) with rotated square shaped slot, (b) with fractal slot etched out from the ground plane.

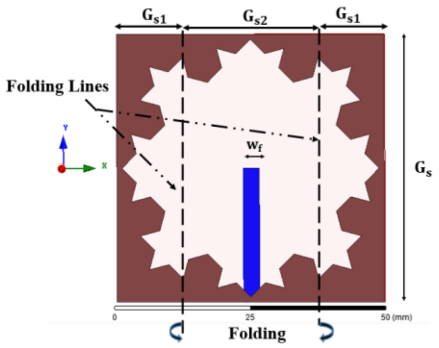


Fig. 2. Geometry of antenna with folding positions (Rear view).

The folding lines are defined at $G_{s2} = 2\,G_{s1} = G_s/2$. After folding the slotted ground plane of antenna is subdivided into three parts: two planar structures of size $G_{s1} \times G_s$ and one planar structure with size $G_{s2} \times G_s$ as shown in Fig. 2.

The proposed 3-D antenna with the substrate and ground plane is shown in Fig. 3. The microstrip feed line is given at top of the structure where the distance between folding lines and feeder are kept 0.05λ apart.

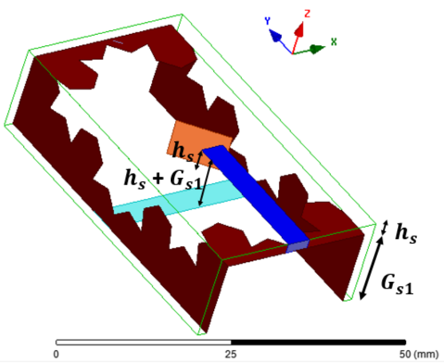
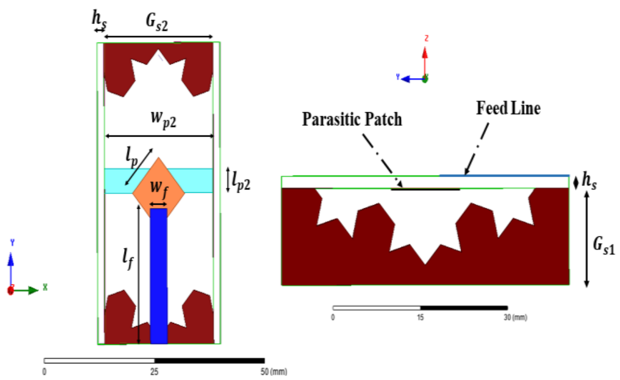


Fig. 3. Structure of the proposed antenna.

Increasing G_{s1} much more than G_{s2} results in reduction in bandwidth of antenna due to large capacitive/inductive reactance. Similarly smaller value of G_{s1} reduces directivity of the antenna. To compensate the reduction of resistivity due to coupling between slotted ground planes and increment in capacitive reactance, a parasitic patch of dimension $(l_p \times l_p)$ is used in the wide slot area as shown in Fig. 4.



(a) (b)

Fig. 4. Structure of proposed antenna (a) Top view. (b) Side view.

Another parasitic patch of dimension $(w_{p2} \times l_{p2})$ is also connected at the bottom of the structure to cancel out the coupling between first parasitic patch and connecting strips (Fig. 4(a)). It helps to obtain proper impedance matching within the desired band. Through the parametric studies, the width of the feed line (w_f) is obtained to be 3.85mm at 50 Ω impedance. Similarly other parameters are given in table 1.

TABLE 1

DETAILS OF STRUCTURAL GEOMETRY (in mm)

Parameter	Dimensions
Length of the substrate (G_s)	50
Height of substrate (h_s)	1.6
Length of the slot (L)	34
Width of the first and third section after folding (G_{s1})	12.5
Width of the middle section after folding (G_{s2})	25
Length of the feed line (l_f)	22.5
Width of feed line (w_f)	3.85
Length of square parasitic patch (l_p)	8.5
Length of rectangular parasitic patch (l_{p2})	25
Width of the rectangular parasitic patch (w_{p2})	4

III. Results and Discussion

Proposed antenna has been simulated using ANSYS HFSS version 15 simulation tool. Fig. 5 demonstrates the reflection

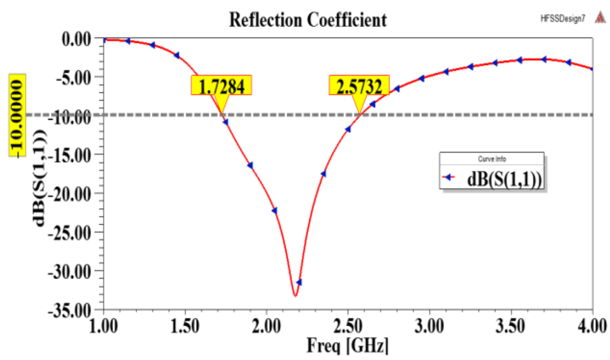


Fig.5. Reflection coefficient variation for proposed antenna.

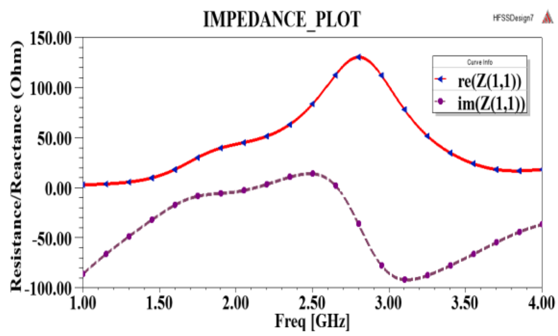


Fig. 6. Input impedance characteristics for proposed antenna.

coefficient variation of the structure.

It shows -10 dB bandwidth in the range of 1.72-2.57 GHz. The plot represents a fractional bandwidth of 39.53% for center frequency at 2.15 GHz.

The impedance characteristic of the antenna is shown in Fig. 6. It clearly indicates the impedance matching at resonance frequency of 2.15 GHz.

The surface current distribution of antenna is shown in Fig. 7 at 2.15 GHz. It is observed clearly that maximum current occurs at center of slot area.

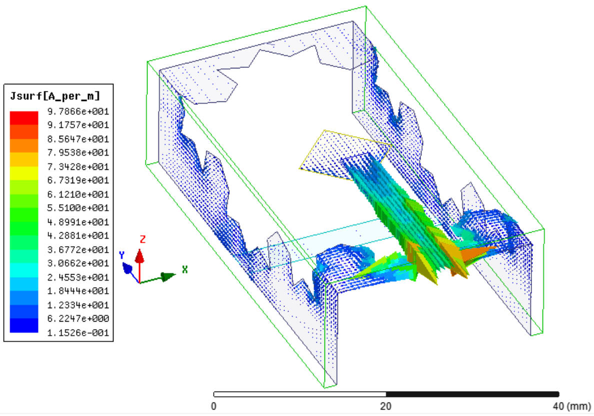


Fig. 7. Surface current distribution at resonance frequency 2.15 GHz.

VSWR characteristics also confirm VSWR ≤ 2 at 1.71-2.59 GHz which indicates the proper impedance matching within the band and shown in Fig. 8.

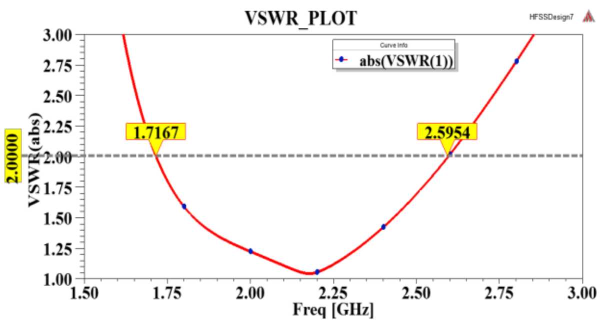


Fig. 8. VSWR variation for proposed antenna.

The peak gain of antenna is observed to be 3.1dB at resonance frequency and it is shown in Fig. 9.

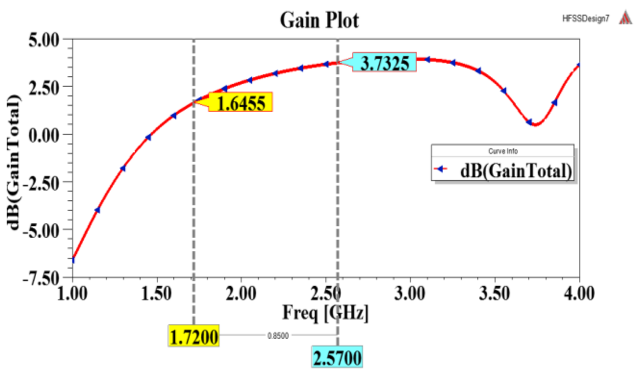


Fig. 9. Peak gain variation for proposed antenna.

The simulation results indicate the front-to-back ratio (FBR) in positive Z-direction around 5dB at maximum operating frequency. The 3D polar plot of the antenna is shown in Fig. 10.

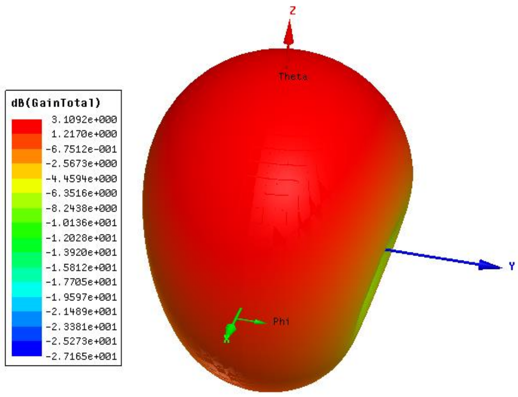
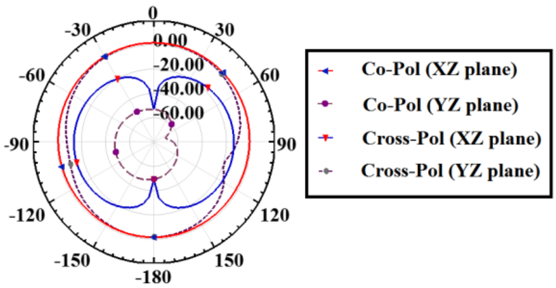


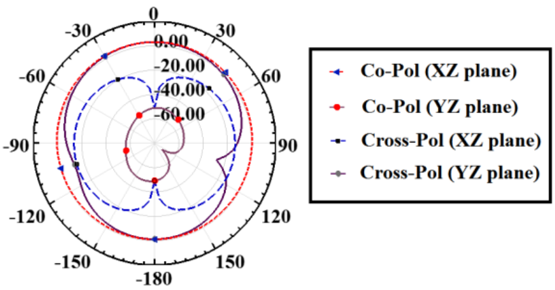
Fig. 10. 3D polar plot for proposed antenna at resonance frequency 2.15 GHz.

It shows a maximum peak gain of 3.1 dB at resonance frequency.

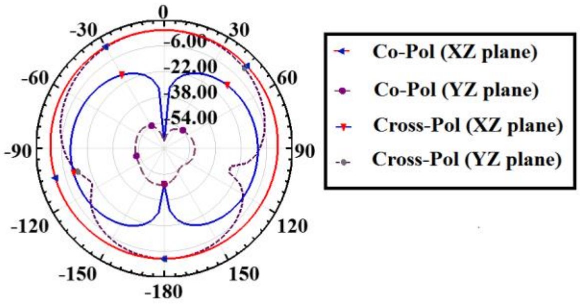
Fig. 11 shows the radiation patterns obtained at three different frequencies i.e. 1.72 GHz, 2.15 GHz, and 2.57 GHz. The results indicate that cross polarization level is at -20dB and -40 dB low at 2.15GHz in XZ-plane and YZ-plane respectively.



(a)



(b)



(c)

Fig. 11. Radiation pattern at (a) 1.72 GHz. (b) 2.15 GHz. (c) 2.57GHz

IV. Conclusion

A compact folded 3-D microstrip antenna has been investigated. Antenna is designed using the combination of the rotated slot and the Koch curve shaped fractal corrugated structure. Reduction in size of the antenna has been achieved using folding technique. The compact antenna with dimension $0.14\,\lambda \times 0.29\,\lambda \times 0.07\,\lambda$ shows -10dB fractional bandwidth of 39.53 %, peak gain of 3.1 dB, and efficiency more than 94% throughout its operating bandwidth. The low operating frequency criteria make the antenna suitable to be used for biomedical applications.

References

[1] S. Ahdi Rezaeieh, A. Zamani, and A. M. Abbosh, "3-D Wideband Antenna for Head-Imaging System with Performance Verification in Brain Tumor Detection," *IEEE Antennas and Wireless Propag. Lett.*, vol. 14, pp. 910-914, 2015.

[2] S. A. Rezaeieh and A. M. Abbosh, "Wideband and unidirectional folded antenna for heart failure detection system," *IEEE Antennas Wireless Propag. Lett.*, vol. 13, pp. 844–847, 2014.

[3] A. T. Mobashsher, A. M. Abbosh, and Y. Wang, "Microwave system to detect traumatic brain injuries using compact unidirectional antenna and wideband transceiver with verification on realistic head phantom," *IEEE Trans. Microw Theory Tech.*, vol. 62, no. 9, pp. 1826–1836, Sep. 2014.

[4] Md. Delwar Hossain, A. Sanagavarapu Mohan, and M. J. Abedin, "Beamspace Time-Reversal Microwave Imaging for Breast Cancer Detection," *IEEE Antennas and Wireless Propag. Lett.*, vol. 12, pp. 241-244, 2013.

[5] X. Li, M. Jalivand, Y. Sit, and T. Zwick, "A compact double-layer on-body matched bowtie antenna for medical diagnosis," *IEEE Trans. Antennas Propag.*, vol. 62, no. 4, pp. 1808–1816, Apr. 2014.

[6] A. T. Mobashsher and A. Abbosh, "Slot-loaded folded dipole antenna with wideband and unidirectional performance for L-band applications," *IEEE Antennas Wireless Propag. Lett.*, vol. 13, pp. 798–801, 2014.

[7] S. Mustafa, B. Mohammed, and A. Abbosh, " Novel Preprocessing Techniques for Accurate Microwave Imaging of Human Brain," *IEEE Antennas and Wireless Propag. Lett.*, vol. 12, pp. 460-463, 2013.

[8] S. A. Rezaeieh, A. Abbosh, and Y. Wang, "Wideband Unidirectional Antenna of Folded Structure in Microwave System for Early Detection of Congestive Heart Failure," *IEEE Tran. Antennas Propag.*, vol. 62, no. 10, pp. 5375–5380, Oct. 2014.

[9] C. Kruesi, R. Vyas, and M. Tentzeris, "Design and development of a novel 3-D cubic antenna for wireless sensor networks (WSNs) and RFID applications," *IEEE Trans. Antennas Propag.*, vol. 57, no. 10, pp. 3293–3299, Oct. 2009.

[10] D. H. Werner, and Raj Mittra, *Frontiers in Electromagnetics*, 1st Edn. IEEE Press, New York, 2000.