# Design and Study of a Small Implantable Antenna Design for Blood Glucose Monitoring

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***Abstract* —** In this paper, a miniaturized implantable antenna with the dimensions of 8×8×1 $mm^3$ has been studied for continuous monitoring of Blood Glucose Levels (BGL). The antenna performance is analyzed numerically for both the free space and implanted operation. The results show that the works excellently in both the scenarios. The antenna has the lowest resonant frequency of 3.58 GHz in free space with a gain 1.18 GHz while it operates at 2.58 GHz with a gain of 4.18 dBi. Good performance, small size and resilience to the human body effects make the antenna to have a good potential use in future implantable glucose monitoring devices.

***Index Terms* —** Implantable, glucose monitoring, small antennas, tele-health systems.

## I. INTRODUCTION

Diabetes, the most worried threat to the modern people, has brought about substantial economic loss not only to people with them but also to the public health system and national economy system [1]. According to [2], effective diabetes management could reduce the risk of the complications associated with the disease; therefore, real time monitoring techniques are indispensable. Among these techniques, implanted glucose sensors attract a lot of interest [3], [4] and various implanted antenna are designed [5]–[8], where the miniaturization of the antenna with high performances is still a great challenge. To realize such antennas, several methods like high-permittivity substrates, fractal structures, shorting pins loading and *etc.* have been studied [9]. The high permittivity method and split-ring resonator (SRR) are more commonly used techniques. In [6], the miniaturization was completed realizing an antenna size of 8.5×8.5×1.27 $mm^3$ by loading C-shaped slots and Complimentary Split-Ring Resonator (CSRR) on the radiation patch. However, there is a need to further decrease the size of the antenna to meet the requirements of continually miniaturizing implantable devices.

In this paper, following the work in [6], efforts are made to further reduce the antenna size. A smaller implantable antenna size is realized for glucose monitoring located in subcutaneous layer of the human tissues with the techniques of the Complimentary Split-Ring Resonator (CSRR) and high permittivity substrates. The antenna performance is studied for the free space and implanted in-body operation through numerical modeling and analysis.

The paper is organized as follows: Section II

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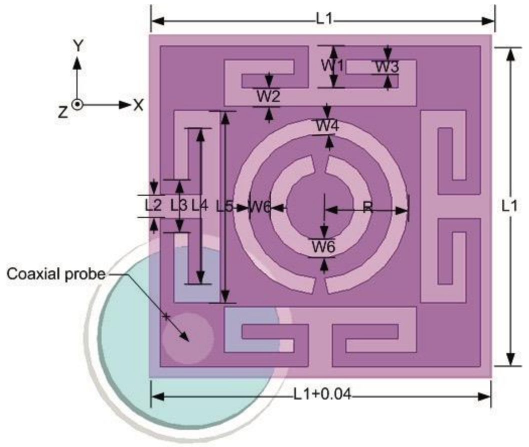
presents the configuration of the proposed implantable antenna and the numerical model of the human body phantom with antenna injected in the subcutaneous layers. Section III gives the analysis of the antenna performance in terms of numerical results. Conclusions are drawn in Section IV.

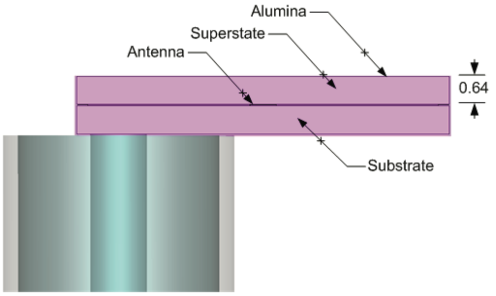
## II. ANTENNA DESIGN AND DISCUSSION

### A. Antenna design

The structure of the proposed antenna is shown in Fig. 1, while the corresponding geometrical parameters are given in Table 1. The antenna is modeled and simulated using Computer Simulation Technology (CST) Microwave Studio package. The substrate and superstate used are the lossy Rogers TMM 13i ($\varepsilon_r$ = 12.85, *tan*δ=0.0019) with a height of 0.5 *mm*. The patch and ground are all considered as Perfect Electric Conductors (PEC) for simplification having the length and width of same size as the substrate and thickness of 35 μ*m*.



(a) Front view



(b) Side view

Fig. 1. Top and side view of the geometrical structure of the proposed implantable antenna.

The antenna is fed through a 50 ohm coaxial probe. The SMA connector is also modeled as shown in Fig. 1 (b). The inner and outer conductors of the SMA connector are modeled as PEC while the coaxial conductor has a $\varepsilon_r$ = 2.1 and μ = 1. To alleviate the effects of the human tissues, the antenna is covered in a film made of Alumina with $\varepsilon_r$ = 9.2, *tan*δ = 0.008 and a thickness of 0.02 mm, as shown in the Fig. 1.

Table 1: Structural parameters of the proposed antenna

| Antenna Parameter | Value (mm) |
|---|---|
| $W_1$ | 1.05 |
| $W_2$ | 0.45 |
| $W_3$ | 0.35 |
| $W_4$ | 0.4 |
| $W_5$ | 0.5 |
| $W_6$ | 0.45 |
| $L_1$ | 8.0 |
| $L_2$ | 0.6 |
| $L_3$ | 1.3 |
| $L_4$ | 3.9 |
| $L_5$ | 4.8 |
| $R$ | 2.2 |

### B. Numerical phantom model

To test the antenna in implantable conditions, a three-layer numerical phantom of the human body is modeled and used in the CST Microwave Studio. The phantom has an overall size of 80×80×38 $mm^3$ as depicted in Fig. 2. The phantom consists of three layers, i.e., skin, fat, and muscle. The electrical parameters (the relative permittivity and the conductivity) in the Industrial, Scientific and Medical (ISM) band (which is our targeted operation region) are given in Table 2. The proposed antenna is implanted in the human body skin at a depth of 2 mm from the body surface.

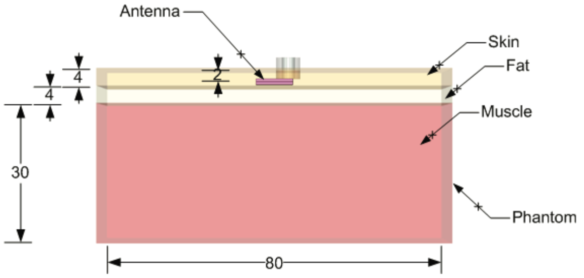
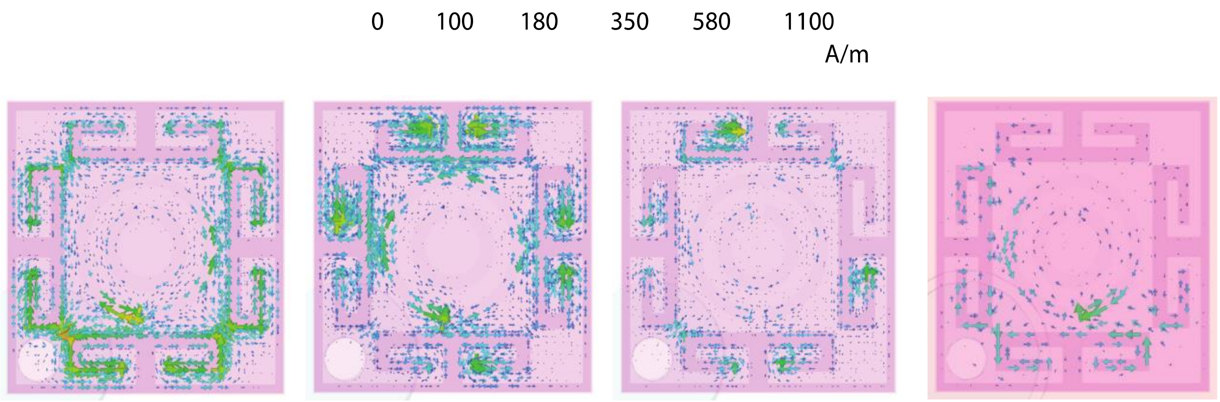


Fig. 2. Schematics of three-layer phantom with antenna implanted at a depth of 2 mm in the skin layer.

Table 2: Electrical properties of the three-layer human body phantom used to test the antenna performance in implantable conditions [10], [11]

| Tissue Layer | $\varepsilon_r$ | σ (*S/m*) |
|---|---|---|
| Skin | 38 | 1.44 |
| Fat | 5.28 | 0.1 |
| Muscle | 52.7 | 1.74 |



(a) 3.75 GHz (b) 11 GHz (c) 14 GHz (d) 2.58 GHz (implanted)

Fig. 3. Surface current distribution for proposed antenna's operation in free space at 3.75 GHz, 11 GHz and 14 GHz and in implantable condition at 2.58 GHz.

## III. NUMERICAL RESULTS AND ANALYSIS

The antenna performance is analyzed in terms of surface current distribution, reflection coefficient, radiation pattern and gain in free space and implanted configurations. Figure 3 shows the current distribution on the antenna surface for the two operational conditions at free space frequencies of 3.75 GHz, 11 GHz and 14 GHz and implanted frequency of 2.58 GHz. It shows that the current path has increased with the introduction of the slots and CSRR in the patch thus lowering the resonant frequency.

The reflection coefficient ($S_{11}$) response of the proposed antenna in free space and in the phantom are shown in Fig. 4. It can be seen that the resonance frequency changes from 3.75 GHz in free space to 2.58 GHz with excellent impedance matching for the antenna in implanted condition. For the free space case, the antenna has various parasitic resonances in the higher frequency band but it has limited effect on the antenna performance when the antenna is implanted in human body.

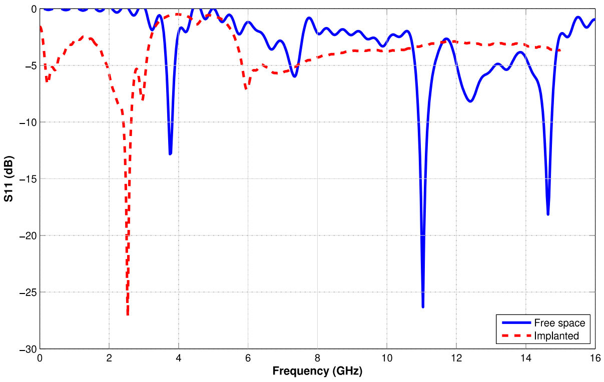
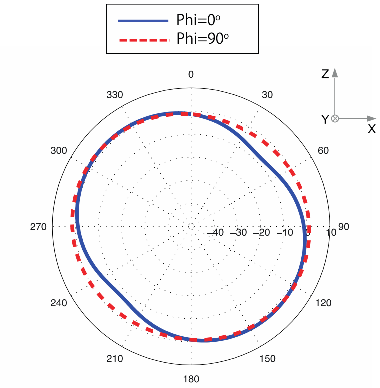
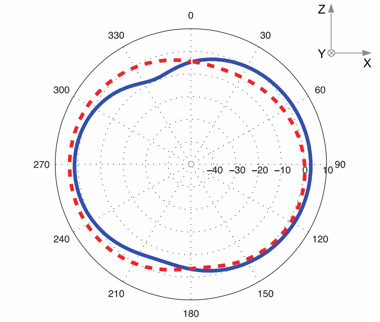


Fig. 4. Reflection coefficient response of the antenna with phantom and without phantom.

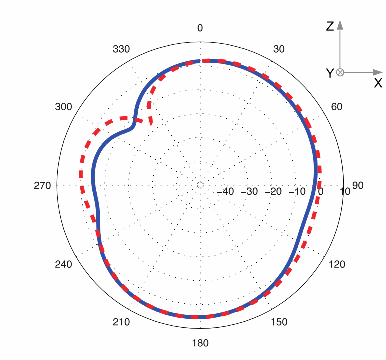
The radiation patterns are observed at 3.75 GHz, 11 GHz and 14 GHz for the free space operation while at 2.58 GHz for the implanted scenario as illustrated in Fig. 5. These results indicate that the antenna has good radiation coverage in both *Phi* ($\phi$) = $0^o$ and *Phi*($\phi$) = $90^o$ planes with nearly omni-directional far-field at all the observed frequencies. More tellingly, the antenna successfully maintains the pattern shape and coverage in both the planes when implanted into the skin tissues as evident from Fig. 5 (d). The near-omnidirectionallty helps the antenna to send and receive the signal/ information in all directions, hence mitigating possible body posture and shape implications.



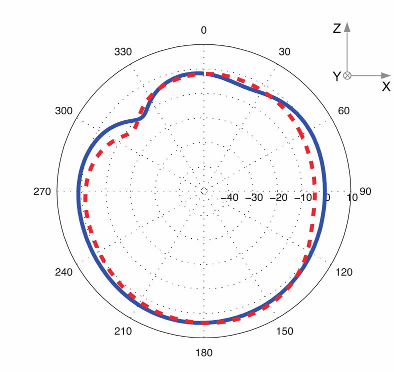
(a) $f$ = 3.75 GHz



(b) $f$ = 11 GHz



(c) $f$ = 14 GHz



(d) $f$ = 2.8 GHz (implanted)

Fig. 5. Radiation patterns of the proposed antenna at different frequencies for free space and implanted operation.

Figure 6 illustrates the simulated peak gain of the proposed antenna in free space and implanted scenarios. It is evident that the proposed antenna offers a good gain performance in all working conditions. The antenna achieves the highest gain of 5.48 dBi at 14 GHz in free space while a very good gain of 4.18 dBi in the implanted configuration.

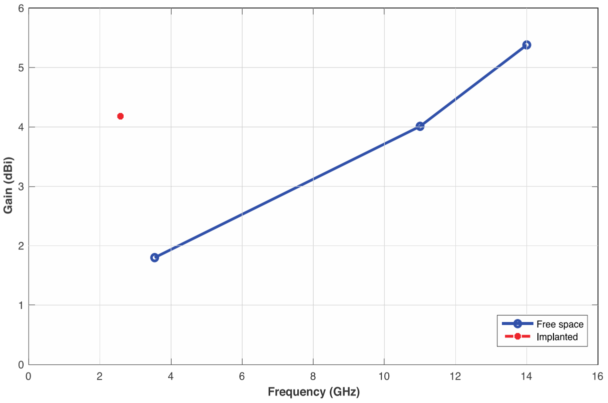


Fig. 6. Peak gain of the proposed antenna in free space and implanted conditions.

## VI. CONCLUSION

A miniaturized implantable antenna with the dimension 8×8×1 $mm^3$ has been studied for the free space and implanted in the skin working conditions in this paper for continuous blood sugar monitoring. The antenna performance is analyzed numerically using a three-layer human body phantom consisting of skin, fat and muscle tissues. The results have shown that a peak gain of 4.18 dBi could be obtained despite the small size of the antenna at the frequency of 2.58 GHz when implanted in body. The antenna also offers good near-omnidirectionality in the radiation pattern. Low profile, small size, good gain and resilience to the human body effects make this antenna a good candidate for tele-health monitoring systems.

## REFERENCES

[1] World Health Organization, *Global report on diabetes*, World Health Organization, 2016.

[2] Horizon Scanning Research and Intelligence Centre, *New and emerging non-invasive glucose monitoring*, Horizon Scanning Research and Intelligence Centre, 2016.

[3] P. S. Hall and Y. Hao, *Antennas and Propagation for Body-Centric Wireless Communications*. Artech House, 2012.

[4] Q. H. Abbasi, M. Ur-Rehman, K. Qaraqe, and A. Alomainy, "Advances in body-centric wireless communication: Applications and state-of-the-art," *The IET, (UK)*, 2016.

[5] Y Cho and H Yoo, "Miniaturised dual-band implantable antenna for wireless biotelemetry," *Electronics Letters*, 52(12):1005-1007, 2016.

[6] X. Y. Liu, Z. T. Wu, Y. Fan, and E. M. Tentzeris, "A miniaturized CSRR loaded wide-beamwidth circularly polarized implantable antenna for subcutaneous real-time glucose monitoring," *IEEE Antennas and Wireless Propagation Letters*, 16:577-580, 2017.

[7] T. Yilmaz, R. Foster, and Y. Hao, "Broadband tissue mimicking phantoms and a patch resonator for evaluating noninvasive monitoring of blood glucose levels," *IEEE Transactions on Antennas and Propagation*, 62(6):3064-3075, 2014.

[8] M. Ur-Rehman, N. A. Malik, X. Yang, Q. H. Abbasi, Z. Zhang, and N. Zhao, "A low profile antenna for millimeter-wave body-centric applications," *IEEE Transactions on Antennas and Propagation*, 65(12):6329-6337, Dec. 2017.

[9] H. Li, Y.-X. Guo, C. Liu, S. Xiao, and L. Li, "A miniature-implantable antenna for medradio-band biomedical telemetry," *IEEE Antennas and Wireless Propagation Letters*, 14:1176-1179, 2015.

[10] S. Gabriel, R. W. Lau, and C. Gabriel, "The dielectric properties of biological tissues: II.

Measurements in the frequency range 10 Hz to 20 GHz," *Physics in Medicine and Biology*, 41(11):2251-2269, 1996.

[11] Dielectric properties. ITIS website. http://www.itis.ethz.ch/virtual-population/tissue-properties/database/dielectric-properties)

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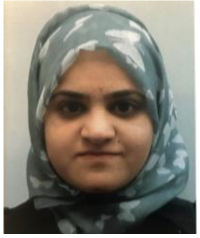

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