Design of a SiC Implantable Rectenna for Wireless In-Vivo Biomedical Devices

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Abstract—**Radio frequency energy harvesting methods for wireless applications have been widely investigated, however limited number of these methods have been capable of generating sufficient energy levels, in which can be leveraged as feasible sources for implantable medical devices, in particular implantable rectenna. Such rectennas can provide unlimited energy for the lifespan of implanted devices. This paper presents a fabricated rectenna using the biocompatible material Silicon Carbide (SiC) and a rectifier system including matching network of 47.7% power efficiency. The developed SiC rectenna is intended for wireless biomedical power transmission. This proposed SiC rectenna has the potential to extend the battery life of implantable medical devices.**

***Index Terms*—Silicon Carbide, implantable medical devices (IMD's), rectenna, rectifier, power transmission, biocompatible, RF Energy.**

I. INTRODUCTION

RADIO frequency (RF) energy harvesting systems are increasingly required in order to satisfy the needs of wireless applications [1]. A major design factor here for these harvesting models is the improvement of its environmental compatibility and adaptability without the detriment of optimum performance levels. Generally, traditional power sources for biomedical applications using RF wireless harvesting systems have gained a considerable attention recently as proposed in [2]-[8], where prior work here focused on longer distances applications. Most notable methods here are inductive and capacitive coupling in [7], magnetodynamic coupling, as well as far-field radio frequency methods such as rectenna in [8].

In addition, implantable systems have gained a considerable attention in biomedical telemetry literature. Now in contrast to wearable systems for body communications, implantable rectennas features more challenges. This is attributed to the compact size of such rectennas, biocompatibility, power efficiency, life span of implantable medical devices. The aforementioned challenges should be taken into consideration in the design phases of implantable rectennas. An implantable rectenna is the key for designing implantable medical devices (IMD's).

II. RF ENERGY SOURCES (RECTENNA)

Significant innovations of the last century have ushered continuous progress in many areas of technology, especially in the form of miniaturization of RF energy sources. As shown in Fig. 1, Most of rectenna designs consist of three basic parts: an antenna, matching network to maximize the power delivered to the load, and a rectifier circuit [9]-[11]. The main component of rectification process is Schottky diode which is less power consumption, faster switch, and less voltage drop than regular diodes. The selection of Schottky diode depends on forward voltage, power requirements, *I-V* characteristics, and maximum reverse breakdown voltage, current voltage characteristics is defined as [12]-[14]. In this paper, the voltage doubles using two high frequency Schottky diodes.

$$I_{\mathrm{D}}=I_{\mathrm{S}}\left[exp\left(\frac{V}{NKT}\right)\text{-}1\right], \quad (1)$$

where I_{D} here denotes the diode current, I_{S} represents the reverse saturation current, V is the forward bias voltage, K symbolized the Boltzmann constant, T denotes the absolute temperature, and finally N is the ideality factor. Now since the rectenna model in this paper is designated for biomedical devices, the material used in antenna design here is biocompatibility material Silicon Carbide (SiC). Furthermore, matching network is a major subsequent stage in the design process, where efficient matching network is mandatory in order to achieve the maximum power transfer accompanied by minimum return loss (S_{11}). In this paper, the matching network fabrication is designed based upon the load impedance, source impedance, and the specifications of the Schottky diodes. Thereafter, built-in optimization tool is applied in Advanced Design System (ADS) software repository. In addition, direct current (DC) block capacitor and smoothing capacitor were also composed into the design model.

III. SIC ANTENNA

In general, the antenna efficiency is a highly substantial design and performance metric, i.e. since it tremendously impacts the amount of losses within the structure of the antenna. These losses are due to conduction, dielectric losses and the reflection. Now rectennas design in lossy material such as the human body is extremely challenging. This is dominantly caused by reduction in antenna efficiency, impedance matching, the electrical impact of the surrounding environment, in addition to the requirement of reduced antenna size. The proposed 10 GHz antenna is shown in Fig. 2 and Fig. 3 as well.

Furthermore, a 4H-SiC semi-insulating substrate is an ideal substrate choice for the antenna because it has no microwave signal loss, thus yielding in maximum achievable antenna efficiency. Now based upon simulation of the same antenna structure, the metal patch antenna is fabricated using a semi-insulating 4H-SiC substrate. A high dielectric constant (ε_r~10) semi-insulating 4H-SiC semiconductor substrate was purchased for this work. Standard photolithography and e-beam evaporation were used for fabrication and metal deposition, which is shown in Fig. 2. One of the most important parameters of an antenna is its return loss. Fig. 3 shows the simulated return loss of the SiC antenna for a 10 GHz antenna structure. It can be observed from Fig. 3 that the SiC antenna resonates at 10 GHz with an (S_{11}) of -15.2 dB. The fabricated antenna is shown in Fig. 4 [15], [16].

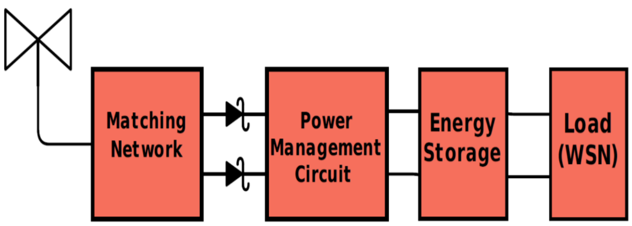

Fig. 1. Block diagram of RF energy harvesting system.

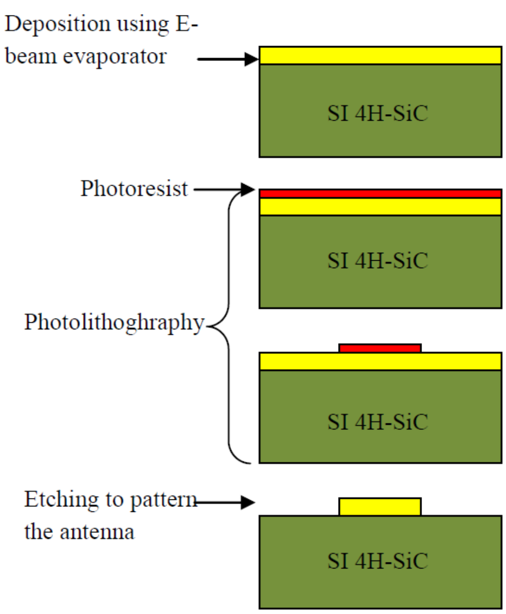

Fig. 2. Fabrication process for the SiC antenna.

Many studies have been performed on amount of generated power from Rectenna such as work in [10], [14], [17]-[19] which showed the generated power range from (10μW) to (1W) but this power range varies with distance, path loss, antenna gain, and frequency. The efficiency of rectenna is measured by *RF-DC* ratio as shown in expressions. (2)-(4).

$$\eta_{\text{DC-RF}}=\frac{P_1}{P_{\text{RF}}}, \tag{2}$$

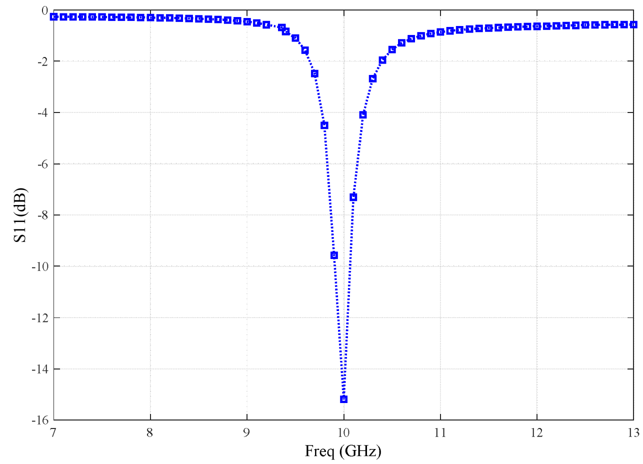

Fig. 3. Simulated return loss (RL) for the SiC antenna.

$$P_{\text{RF}}=P_{\text{density}}*Ae, \tag{3}$$

$$Ae=\frac{\lambda^2 G}{4\pi}, \tag{4}$$

where P_{density} is the power density, P_1 denotes the output power of rectenna, Ae represents the effective area for the patch antenna, λ is wavelength, where $\lambda=c/f$, here c and f in order represent the speed of light and operating frequency. Finally the parameter G in expression (4) symbolizes the antenna gain. Note that the effective area of patch antenna is larger than the physical area, which is usually caused by the fringing field effect. Typically, antennas are trimmed by 2-4% in order to mitigate this effect and achieve resonance at the desired operating frequency as discussed in [18].

Now in order to compute the effective area of the patch antenna, expressions (5) through (7) in [20] are adopted here, i.e., to calculate the actual (L_p) and effective (L_{eff}) length of the patch antenna, given by:

$$L_p = L_{eff} - 2\Delta L \tag{5}$$

$$L_{eff} = \frac{c}{2f\sqrt{\varepsilon_e}} \tag{6}$$

$$\Delta L = 0.412 h_p * \frac{\left\{(\varepsilon_e + 0.300)*\left(\frac{w}{h_p}+0.264\right)\right\}}{\left\{(\varepsilon_e - 0.258)*\left(\frac{w}{h_p}+0.813\right)\right\}} \tag{7}$$

where ΔL is the extended patch length, ε_e is the effective dielectric constant, h_p is the height of the patch, and w is the width of the patch.

Fig. 5 depicts a layout of rectifier stage using Roger RO4350B [21], which will be coated as potential future work. Here this circuitry (Roger RO4350B) features favorable merits, such as ease of integration and fabrication, as well as low loss features that contribute for enhanced power efficiency. Furthermore, the matching network is realized with microstrip lines in order to achieve maximum efficiency.

Fig. 4. Simulated and fabricated antenna.

IV. SIMULATION RESULTS

The simulated DC-RF efficiency and input power for the developed implantable rectenna is presented in Fig. 6. A conversion efficiency of 47.7% is achieved for an optimum load. The efficiency curves in Fig. 6 show that the rectenna maximum efficiency point over a range of received power levels can be reached with optimum load impedance. For the rectenna of Fig. 4, this resistance is 400 Ω. Consequently, the rectifier was designed based upon the above remarks, where favorable efficiency levels of 47.7% were achieved.

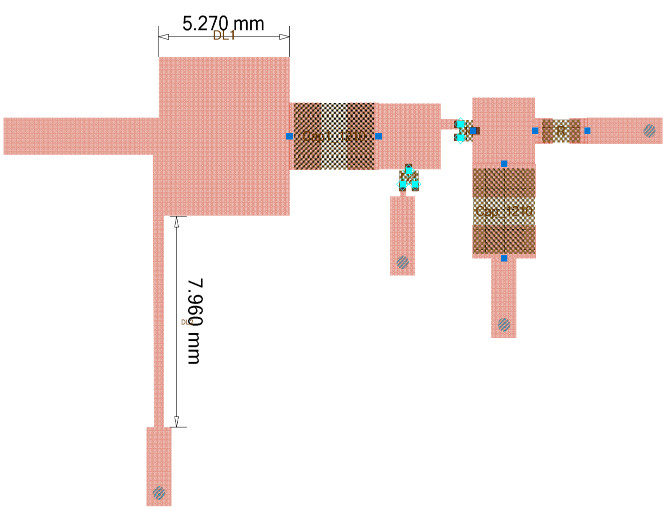

Fig. 5. Layout of rectifier stage with matching network.

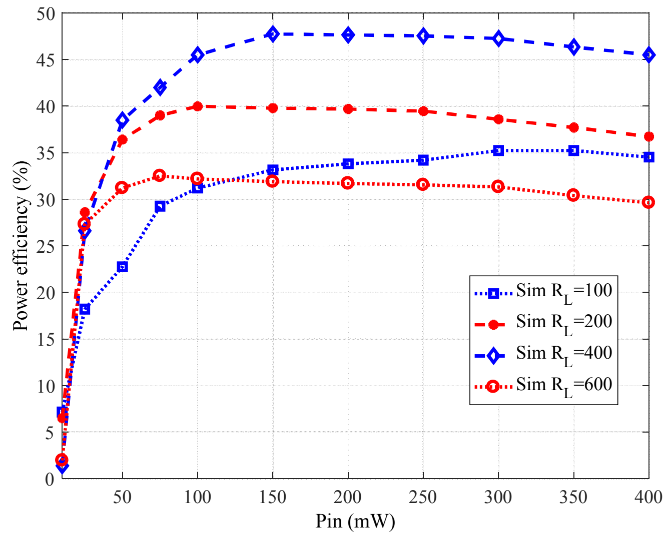

Fig. 6. Power efficiency for the proposed Rectenna design.

V. CONCLUSIONS

This paper presents a fabricated rectenna using the biocompatible material Silicon Carbide (SiC) and a rectifier system including matching network with 47.7% power efficiency. The developed SiC rectenna is intended for wireless biomedical power transmission. This proposed SiC rectenna has the potential to extend the battery life of implantable medical devices. Results demonstrate that the maximum converter efficiency of rectenna design is 47.4% for optimum R_L= 400Ω. Therefore it can be applied with RF energy sources with low load resistance. Future work will further investigate and address the biocompatibility challenge for the implantable rectenna, since the antenna is designed using Silicon Carbide. Also, rectifier stage will be coated using a thin layer of biocompatible material, in order to be used for biomedical applications.

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