# Effect of Implant Coating on Wireless Powering for Intracranial Pressure Monitoring System

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*Abstract—* **A fully wireless implantable system can be used for long-term monitoring of intracranial pressure. In this type of system, an implant is placed under the skull and monitored pressure is transmitted wirelessly outside the skull. Moreover, the implant is powered through an inductive coupling. To avoid any infection and damage to the implant, the implant should be coated with biocompatible material. In this paper, we investigate the impact of coating on the maximum wireless link power efficiency through simulations in anatomical and layered tissue head models and present test results.**

*Keywords— Wireless Power transfer, Intracranial Pressure (ICP) and biocompatible coating.*

## I. INTRODUCTION

Long-term monitoring of intracranial pressure (ICP) has the potential to improve the safety of people predisposed intracranial hypertension (IH) due to an illness, such as idiopathic IH or hydrocephalus, or as a result of a previous neurocritical event. [1-2]. Current ICP monitoring methods depend on the placement of a monitoring device. In an invasive method, the monitoring system/sensor is placed inside the skull whereas in a non-invasive method outside the skull. Invasive methods are accurate but suffer from risk of infection whereas non-invasive methods lack in the accuracy [1]. A fully wireless implantable system can overcome the limitations of invasive and non-invasive methods. In this type of a system, an implant is placed under the skull and pressure change is transmitted wirelessly.

In our previous work [3], we have successfully activated the piezoresistive pressure sensor through inductive powering and pressure readout experiment was demonstrated by monitoring the sensor output voltage. A proposed fully wireless implantable system architecture is presented in Fig.1(a). The implant has three main parts. First is energy harvesting unit, second is the pressure sensor and third is data transmission unit. The energy harvesting unit is inductively coupled to an on-body unit and powers the implant. The pressure sensor monitors the pressure. Finally, the data transmission unit transmits the monitored pressure through a far-field antenna [4] which is received by an off-body unit.

The implant should be either composed of biocompatible material or coated with biocompatible material. In this paper, we study the effect of implant coating on the maximum wireless
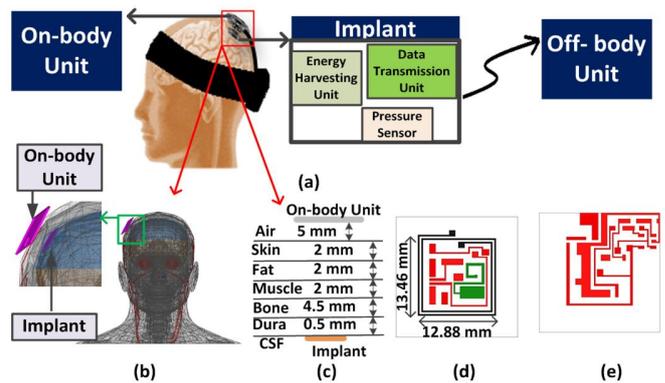
Fig. 1. (a) System level description of proposed system for wireless ICP monitoring (b) anatomical human head model in ANSYS HFSS v15 (c) simplified layered model (d) front side of implant consists of 2-turns coils antenna (black), far-field antenna (green) and traces for other components (red) (e) back side of implant consists of traces for electronic components.

link power efficiency ($G_{p,max}$). Moreover, we have compared the anatomical human head model provided in ANSYS HFSS v15 (Fig. 1(b)) and simplified layered tissue model (Fig. 1(c)) in terms of $G_{p,max}$. Finally, the measured S-parameters of wireless link are presented and $G_{p,max}$ is estimated.

## II. SYSTEM DESIGN AND SIMULATION RESULTS

HFSS v15 is used for $G_{p,max}$ simulation as detailed in [5]. The simulation is done for two different models with and without coating. The first of these is anatomical human head model provided in ANSYS HFSS v15. The second of these is simplified layered tissue model. In this model, each tissue layer is assigned frequency dependent properties as explained in [5]. A biocompatible MED-2000 silicone adhesive coating with an overall thickens of 1 mm is used for both models. In both models, the implant is placed in cerebrospinal fluid (CSF). The on-body unit is placed at 5 mm distance from the skin. The total distance between the implant and on-body unit is 16 mm.

Fig. 1(d-e) shows front and back sides of the implant. It is designed on flexible polyimide substrate with 50 μm thickness. The far-field antenna and copper traces for electronics components attachment are marked with green and red colours, respectively. Moreover, the 2-turns coils antenna is inductively coupled to the on-body unit. The on-body unit consists of 2-turns loop antenna which is presented in [5]. The implant 2-turns coil antenna is presented in [3].
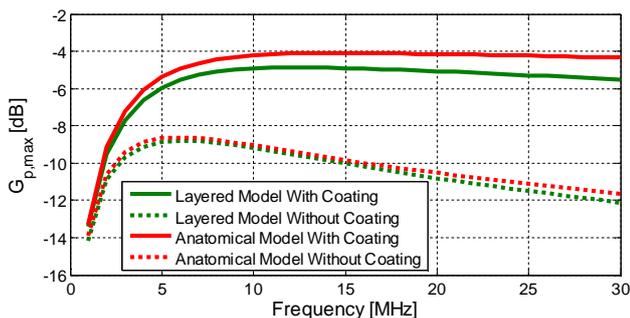
Fig. 2. Simulated maximum wireless link power efficiency for models with and without coating
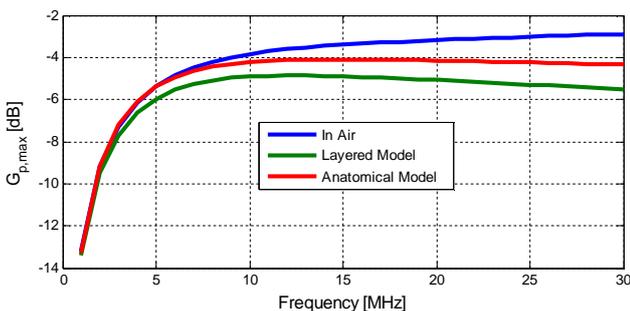


Fig. 3. Simulated maximum wireless link power efficiency in air, anatomical and layered models with coating
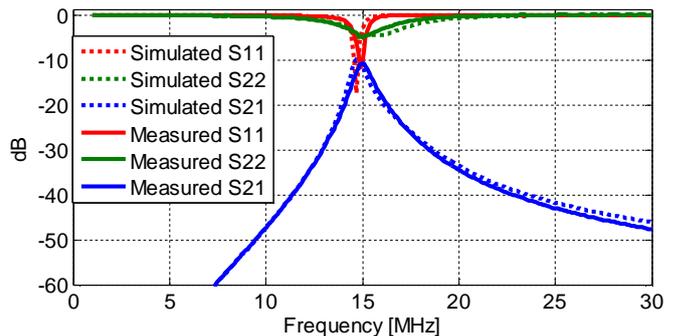


Fig. 4. Simulated and measured S-parameters of the wireless link in air with silicone coated implant

in LC configuration were used for the on-body unit. Whereas, a capacitor (830 pF) in parallel configuration was used for the implant. Then, the implant was coated with biocompatible MED-2 000 silicone adhesive with an overall thickness of 1 mm. Afterward, the 2-port S-parameters were measured through Vector Network Analyze (VNA). Port 1 of the VNA was connected to the on-body unit whereas port 2 to the implant. We measured the S-parameters in air. Fig. 3 shows the simulated $G_{p,max}$ comparison in air, anatomical model and layered tissue model with coating. At our interested frequency of 15 MHz, the air measurement is close to both anatomical and layered tissue models. Therefore, we measured the S-parameters in air.

Fig. 4 shows the simulated and the measured S-parameters at 15 MHz. 2-port S-parameters were simulated in ANSYS Electronics Desktop after adding the matching inductor and capacitor elements. Both simulated and measured S-parameters agree well. The peak of S21 in simulation is at 14.77 MHz whereas in measurement is at 15 MHz. The peak of S21 is – 9.76 dB and – 10.86 dB in simulation and measurement respectively. The measured S-parameters at 15 MHz are: S11= – 11.27 dB, S22= – 4.88 dB and S21= – 10.86 dB. We estimated the $G_{p,max}$ by removing the effect of matching components. The effect of matching components was compensated through simulated insertion loss (4.2 dB) of conjugate-matched matching networks. The simulated and estimated $G_{p,max}$ values are – 3.4 dB and – 4.2 dB respectively.

Fig. 2 shows the simulated $G_{p,max}$ for two models with and without coating. Firstly, they predict very similar frequency dependencies for $G_{p,max}$ with only a minor level difference. Secondly, the silicone coating improves $G_{p,max}$ markedly. This can be explained by the fact that coating increases the distance between the implant 2-turns coil antenna and CSF which exhibits high dielectric loss. At 15 MHz, the improvement in $G_{p,max}$ is approximately 6 dB. Thus, the coating not only delivers the needed biocompatibility, but also improves the performance of the wireless link. Thirdly, the addition of coating produced an upwards shift in the frequency of the peak $G_{p,max}$: from 6 to 12 MHz and 6 to 15 MHz in the layered tissue and anatomical models, respectively. Despite the difference of 3 MHz in the optimum frequency predicted by the two models in the case of a coated implant, it can be seen that there is actually a very broad optimum in both cases. Overall these findings indicate that both models are fit for the modelling of the inductive link. Moreover, simulation with different coating thickness shows no significant effect on $G_{p,max}$ whereas in case of far field antenna [4] it effects the radiation efficiency. Similarly, simulation is done with different relative permittivity values (1 to 5) of coating material and no significant effect on $G_{p,max}$ is observed. An important benefit of the layered model is its adaptability for the estimation of the impact of anatomical variations, such as different thickness of the skull. However, the anatomical model may provide more accurate setting for the simulation of the radiation properties of the far field antenna. Thus, we have chosen 15 MHz for the experimental characterisations.

## III. MEASUREMENT RESULTS AND DISCUSSION

We fabricated the on-body unit and implant. For matching circuit at 15 MHz, an inductor (39 nH) and a capacitor (830 pF)

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