Effects of the Human Body on Wearable Wireless Power Transfer Systems

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***Abstract*—In this paper, the effects of different parts of the human body on a wearable Wireless Power Transfer (WPT) system are examined. A Strongly Coupled Magnetic Resonators (SCMR) WPT system operating in the ISM band 40.68 MHz is used in this study. The results show that when the WPT system is placed directly on the human body its Power Transfer Efficiency (PTE) is reduced by 13% on average in both simulations and measurements. These losses are attributed to the material properties of the human body. Also, different parts of the human body cause different drops in PTE due to their different shapes and geometries.**

***Index Terms*—Human body, wearable, wireless power tranfer, SCMR.**

I. INTRODUCTION

Wireless Power Transfer (WPT) was first introduced by Nikola Tesla in the early 1900s. Since that date, WPT has attracted significant attention by consumer electronics and biomedical applications [1] for implantable [2] and wearable devices [3]. It provides the advantage of supplying power to electronics inside or on the human body without restricting wires and batteries. Many methods have been used to power wearable devices, such as, inductive coupling [2] and Strongly Coupled Magnetic Resonance (SCMR) [4]-[5]. SCMR is typically preferred as it provides high efficiency and longer range. Hence, SCMR method is used in our study since its very well suited for wireless powering wearable devices. However, the human body, where the WPT receiver element (Rx) is placed, has significant influence on the WPT system performance, such as, the operation frequency and Power Transfer Efficiency (PTE). Therefore, these effects must be investigated in advance since the performance of a WPT system degrades when it is placed on the human body depending on its specific location.

II. WIRELESS POWER TRANSFER SYSTEM

A. SCMR Design

The SCMR is a wireless power transfer system that functions using an inner ring, which operates as either a source or load depending on its placement in the circuit, and an outer ring, which is the primary determinant of the resonant frequency of the SCMR. The size of the SCMR as well as other properties, such as the width of the outer ring, have an impact on the performance and the range at which the maxi- mum efficiency is achieved. A larger SCMR operates at larger distance than a smaller one, but wearable and implantable applications impose strict limitations to the size of SCMR systems. In this work, the SCMR design is optimized to have peak performance at 40.68 MHz (ISM band) for a separation of 60mm. A capacitor (C_p= 198 pF) is added to the outre ring, as shown in Fig. 1, to tune the SCMR to the frequency where the structure exhibits maximum Q-factor. The geometry of our design and its measured and simulated PTE are presented in Fig. 1. Specifically, our WPT system exhibits 81% and 70% simulated and measured efficiencies, respectively. This difference between measurements and simulations is attributed to manufacturing imperfections and capacitor tolerances.

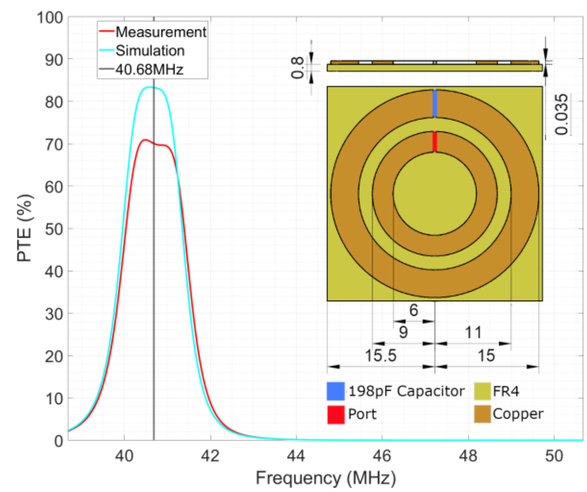

Fig. 1. Simulated and measured PTE versus frequency.

B. SCMR System on the Human Body

The performance of our SCMR is simulated and measured for 26 different locations organized into the following categories: head, neck/bicep, torso, arm and leg, as shown in Fig. 2 (a). Each category had 5 measurement points, except for the torso, which had 6. The simulations were performed in ANSYS HFSS using the ANSYS Human body model. A 3D printed support was used in measurements to maintain a 60mm separation as shown in Fig. 2 (b).

III. RESULTS

The average of the PTE on the different sections at the operating frequency is listed in Table I along with a reference (SCMR operating in free space). These results are reported

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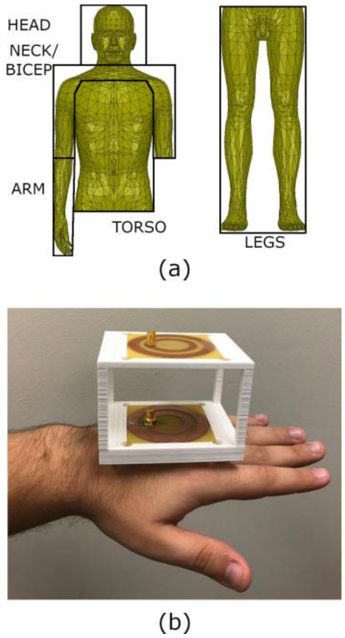

Fig. 2. (a) ANSYS human body model, and (b) 10mm measurement setup on the hand.

TABLE I: PTE (%) on Human Body

Body Part/ Group	**Power Transfer Efficiency**			
	Simulated		*Measured*	
	0mm	*10mm*	*0mm*	*10mm*
REFERENCE	*83.4*		*70.4*	
UPPER BACK[a]	67.2	74.0	50.7	67.6
TOP OF WRIST[b]	72.1	80.0	62.5	69.5
HEAD	69.1	77.0	59.9	66.0
NECK/BICEP	66.0	75.7	57.6	66.0
TORSO	68.6	75.4	54.0	64.2
ARMS	70.5	76.2	60.7	67.4
LEGS	73.2	78.9	53.7	66.9

(a) High loss, (b) Low loss.

for two different distances from the human body (0mm and 10mm). The body parts group with the highest and lowest measured losses were the legs and the arms, respectively. The greatest and lowest losses were observed for the outer thigh and the top of the wrist, respectively, as shown in Table I.

Our results show that the PTE of SCMR systems mainly depends on the mass of the human body behind the receiver. When SCMR loops are placed on body parts that are smaller than their size, then the body does not completely influence the EM fields and in consequence the losses are smaller (i.e., less body absorption). This explains why our WPT system experiences the lowest losses on the arms. Also, this justifies the similarity between groups, such as, the torso and leg regions (which, besides the actual foot, had similar losses to the torso), as they both are larger in volume and area. Additionally, the materials present in different parts of the human body play a significant role in determining the losses of a wearable WPT system. For example, materials such as bone will have less conductivity compared to muscle or fat. Furthermore, organs may have different properties, leading to differences in PTE. This explain why the thigh measurements, neighboring the gluteus maximus and a particularly dense area of the body, have the greatest losses, surpassing the larger torso areas.

The model used in our simulations was an approximate model, and thus not perfectly representative of the human body and its several different components, all with varying electrical properties. This is why the higher and lower loss areas in simulation exhibit a difference of only 5% efficiency, while in measurements the maximum difference of the efficiency in these areas is 12% at 0mm.

IV. Conclusion

In this paper, the effect of different parts of the human body on the PTE of a WPT system in both simulation and measurement were presented. The results showed a tangible difference in term of PTE on different parts of the human body.

Acknowledgement

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