Watt-Level Low-SAR Near-Field Wearable Wireless Power Transfer using an All-Textile Receiver

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***Abstract*—Near-field radiative Wireless Power Transfer (WPT) has the advantage of high-power WPT. In this paper, an all-textile high-power WPT receiver is realized for the first time, using an embroidered coil and a printed tuning capacitor on a textile substrate. The proposed coil is demonstrated receiving over 3 W DC power at 6.78 MHz with a 23% end-to-end efficiency. A low Specific Absorption Rate (SAR) of 0.37 W/kg is observed, through full-wave simulation, for up to 10 W high-frequency input to the on-body coil, demonstrating its suitability for wearable applications.**

I. INTRODUCTION

Enabling wearable devices to be charged wirelessly is a key requirement for power autonomous future textile-based electronics. While a range of wearable textile-based far-field rectennas has been reported [1], [2], their DC output is limited to less than 10 mW due to the Equivalent Isotropic Radiated Power (EIRP) limits [2], and the high expected Specific Absorption Limit (SAR) due to the high tissue absorption.

On the other hand, near-field non-radiative WPT and wave-guiding mechanisms have attracted significant interest for both low-loss communication and WPT [3]. A range of flexible [4], printed [5], and textile-based coils [6], have been reported, with practical demonstrations based on commercial Qi transmitters and receivers up to 1.2 W below 300 kHz [7]. However, there has been no demonstration to date of a wearable WPT receiver operating above 1 W using Magnetic Resonance (MR) WPT. Moreover, while printed coils and tuning capacitors have previously been reported for power electronics applications replacing surface-mount components [8], their high-power (>50 mW) handling remains unknown.

In this paper, we propose an all-flexible textile-based WPT receiver combining an embroidered high-Quality (Q)-factor coil with a laminated screen-printed capacitor, demonstrating nearly 2 W DC output with at least 20% DC-to-DC efficiency, in human proximity. This work demonstrates that textile-based near-field WPT receivers can maintain a high efficiency and power handling while complying with the SAR regulations.

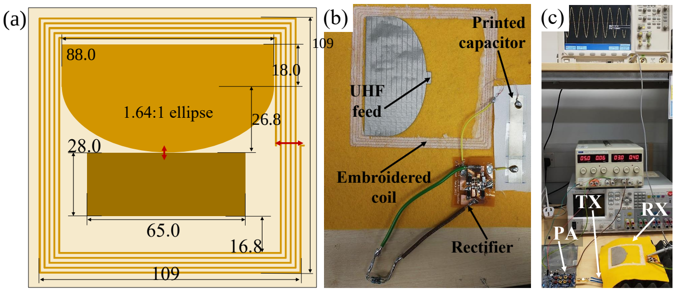

Fig. 1. The near-field WPT antenna: (a) layout and dimensions in mm; (b) photograph showing the printed capacitor; (c) measurement setup.

II. ALL-TEXTILE NEAR-FIELD WPT ANTENNA

The textile-based near-field wireless power receiver is based on the dual-mode antenna in [9], combining a UHF radiating element for communication and far-field WPT with an embroidered square coil with a measured inductance of 6.3 μH. The antenna's layout and dimensions are shown in Fig. 1(a). The coil is tuned to resonate around 6.78 MHz using a 90 pF capacitor. A metal-insulator-metal (MIM) capacitor is realized using screen printing on a polyurethane (PU) film and heat-pressed onto a textile substrate. Screen-printable laminated capacitors have previously been used for microwave DC blocking applications up to 50 GHz, but were only realized with up to 50 pF capacitance and only tested for a 1 W microwave input [10]. A lumped ceramic capacitor (with a 1.5 kV rating) is used for benchmarking. Fig. 1(b) shows the realized antenna with the printed tuning capacitor.

Before characterizing the complete WPT system, the s-parameters of the textile coils were experimentally characterized under critical coupling with a 5-turn circular Litz coil on the transmitting side. The measured s-parameters of the textile coils are shown in Fig. 2 for both the lumped ceramic and printed silver capacitors. The S_{11} in Fig. 2(a) and (b) shows that both coils are well-matched with the printed coil having a a wider bandwidth due to its lower Q-factor. The lower Q also results in a lower peak S_{21} for the printed capacitor as seen in Fig. 2(b).

III. WATT-LEVEL WPT CHARACTERIZATION

The transmitting coil, a 10 cm-radius 5-turn circular Litz coil, was connected to a 50 W GaN Power Amplifier (PA) with a voltage-controllable 6.78 MHz output, as shown in Fig. 1(c). The textile coil was connected to a bridge rectifier based on

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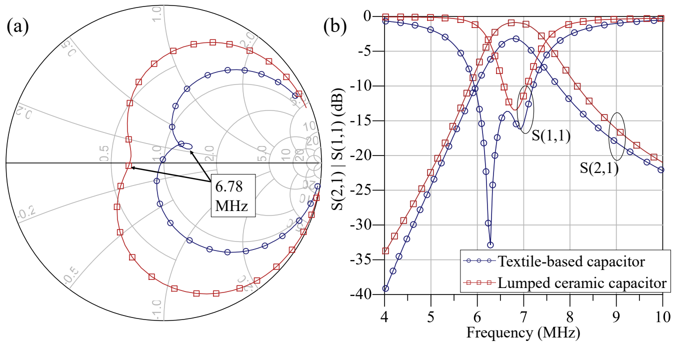

Fig. 2. Measured s-parameters of the textile coil at 5 cm away from a transmitter with a ceramic and printed capacitor: (a) complex Z_{11}; (b) S_{11}; S_{21} magnitudes.

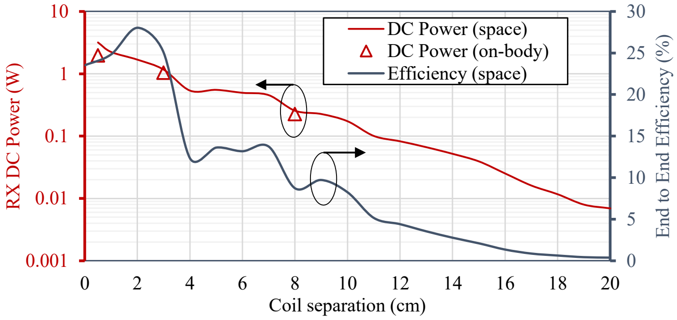

Fig. 3. Measured DC power delivered to the 102 load and the end-to-end DC-to-DC in space and on-body.

Schottky diodes with 1 A and 200 V current and voltage ratings, respectively, on a flexible substrate. The load was fixed at 102 based on harmonic balance rectifier simulations.

The PA's supply has been set to 7.5 V and the DC supply current was monitored. The DC voltage across the load was measured using an oscilloscope. The vertical separation between the aligned transmitting and receiving (textile-based) coils was varied. Fig. 3 shows the DC power delivered to the load for varying coil separation alongside the end-to-end DC-to-DC efficiency. The measured efficiency is inclusive of the PA, coil/capacitor, and rectifier losses and can be further improved by using a more efficient rectifier. From Fig. 3 it can be seen that up to 3.17 and 1.98 W could be delivered to the load at 0.5 cm separation in the absence and presence of a human hand on the coil, respectively. Furthermore, at different separations, the effect of human proximity on the received DC power is minimal. At 20 cm distance between the coils, the power delivered to the load was 6.9 mW; for longer distances, radiative far-field WPT is expected to yield a higher DC output in the order of a few mW [1].

To explore the safety of the proposed high-power coils for on-body use, the critically-coupled coils were simulated in CST Microwave Studio over a layered tissue model, shown in Fig. 4(a). By using loss-less conductors for the coil in the CST model, a more conservative SAR estimate can be obtained where a higher power level will be received by the coil, consequently increasing the human exposure. The simulated power losses in the tissue were used to calculate the SAR distribution for a 10 W input, averaged over 1 g tissue mass. Fig. 4(b) shows the simulated SAR distribution, which is well under the 1.7 W/kg limit of IEEE C95.1 standard.

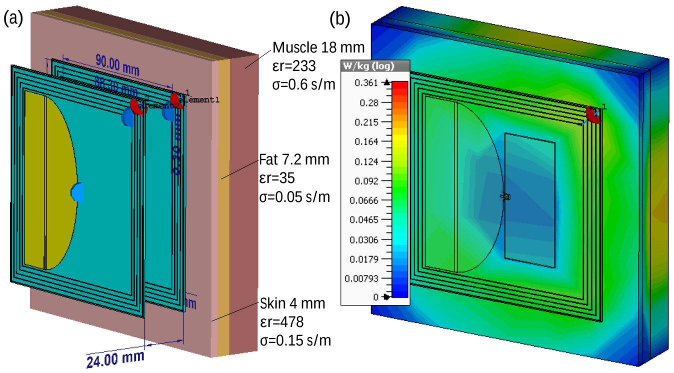

Fig. 4. Simulated SAR at critical coupling: (a) CST model; (b) SAR distribution at 10 W showing a peak SAR=0.37 W/kg.

IV. CONCLUSION

In this paper, an all-textile wearable wireless power receiver was presented based on an embroidered coil and printed tuning capacitor. The resonant coil was demonstrated receiving over 3 W DC power at 6.78 MHz, with an end-to-end efficiency over 20% and a simulated SAR under 0.4 W/kg. The high power handling and comparable efficiency to lumped capacitors demonstrate that future wireless power receivers could be realized using all-flexible components. Future work includes characterizing the thermal reliability of the textile-based coils and capacitors under prolonged high-power excitation.

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