Body-Proximity Effects on the Input Impedance of a Complex-Conjugate SWIPT Textile Rectenna

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***Abstract*—While a range of Simultaneous Wireless Information and Power Transfer (SWIPT) rectennas were proposed for wearables, the human-proximity effects on a complex-conjugate matching network-free rectenna remain mostly unknown. This paper reports for the first time the impact of human proximity on a complex conjugate rectenna's impedance. The impedance of a dual-mode SWIPT microstrip/dipole rectenna is measured experimentally for varying separation from the body and on different body positions. The measured input impedance is used to simulate the rectifier's RF-to-DC efficiency using a non-linear model showing the effects of the power level, load, and frequency on the DC output for different on-body impedances.**

I. Introduction

Wearables are among the key applications which could benefit from Radio Frequency (RF) power transfer and Simultaneous Wireless Information and Power Transfer (SWIPT) [1], using flexible and textile-based rectennas [2], [3], [4], [5]. Wearable antennas operating from sub-1 GHz bands through to mmWave frequencies have been proposed for RF energy harvesting applications. While a range of wearable rectennas have not been isolated from the human body, and were demonstrated maintaining their RF-to-DC Power Conversion Efficiency (PCE) in human proximity [2], [6], both approaches relied on broadband antennas as opposed to resonant complex-conjugate matching [2], [6]. Therefore, the interaction between the body and a complex-conjugate rectenna remains unknown.

Recently, a range of fully textile wearable SWIPT rectennas has been proposed based on shared-aperture multi-port antennas [5], [7]. For a microstrip patch with a solid ground plane [7], the rectenna's impedance is mostly maintained in human proximity. However, for the unisolated "wire-type" dipole rectenna [5], the influence of human proximity on the rectifier's complex conjugate matching remains unknown.

In this paper, the effects of human proximity on a matching network-free shared-aperture dual-band/mode rectenna, from [5], are investigated. Through impedance measurements and non-linear rectifier simulation, it is shown that the rectifier could maintain a high PCE in human proximity when not pressed directly against the skin.

II. Shared-Aperture Wearable SWIPT Rectenna

The antenna considered in this work is based on a novel shared-aperture microstrip patch with an inductive feed for sub-1 GHz operation as a rectenna, with a proximity-coupled 50 Ω microstrip feed [5]. The impedance of the rectifier port can be adapted by varying the length of the slot to match different rectifiers. Fig. 1(a) shows the layout of the antenna, with Fig. 1(b)-(d) showing the measured s-parameters and 3D polarized radiation patterns at the 2.4 GHz port, on a human phantom [5], where a 7.2 dBi gain with a 63% radiation efficiency are maintained. Fig. 1(b) shows the high isolation (over 30 dB) between the communication and rectifier ports, which indicates the antenna's ability to operate simultaneously as a 2.4 GHz transmitter and sub-1 GHz power receiver.

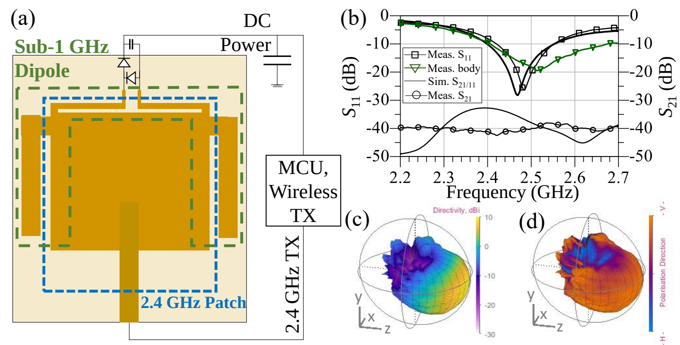

Fig. 1. The shared-aperture dual-band wearable SWIPT antenna: (a) layout (detailed dimensions in [5]; (b) simulated and measured s-parameters; (c) measured 3D directivity; (d) measured polarization.

III. On-Body Impedance Characterization

The input impedance (Z_{in}) of the antenna was measured using a two-port VNA with a common-ground coaxial jig, using the setup shown in the inset of Fig. 2. The length of the feeding inductive slot has been modified from [5], limiting it to 55 mm, to account for the resonance shift in human proximity. $\Im\{Z_{\text{in}}\}$ was measured for a range of on-body positions and is shown in Fig. 2, where it can be seen that the biggest increase in both $\Re\{Z_{\text{in}}\}$ and $\Im\{Z_{\text{in}}\}$ is observed for direct skin contact.

The voltage doubler rectifier, based on the SMS7630 Schottky diode [5], has been simulated in Keysight ADS using non-linear Harmonic Balance simulation, previously shown to maintain a very close agreement with measurement [2]. The source impedance at 868 MHz, the operation frequency of the rectenna, has been set to the measured input impedance for each body part from Fig. 2. First, a power sweep is presented for the optimum load of 20 kΩ at 868 MHz; the simulated PCE and DC voltage are shown in Fig. 3.

Except for the on-skin measurement positions, where the antenna's $\Im\{Z_{\text{in}}\}$ deviated significantly off the unloaded re-

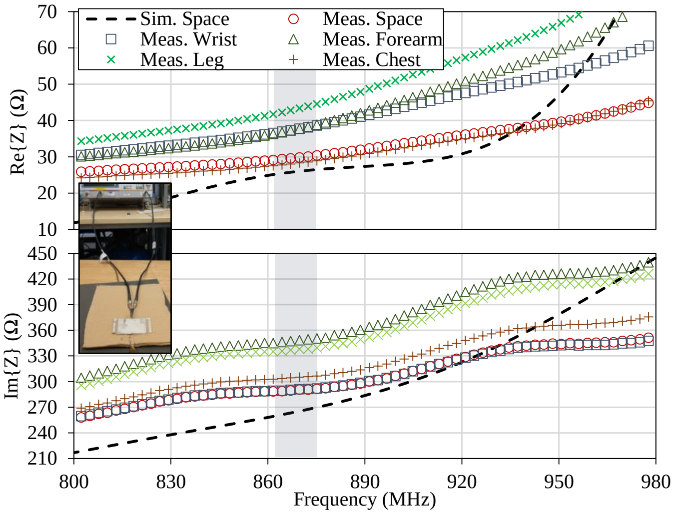

Fig. 2. Measured input impedance for different body parts.

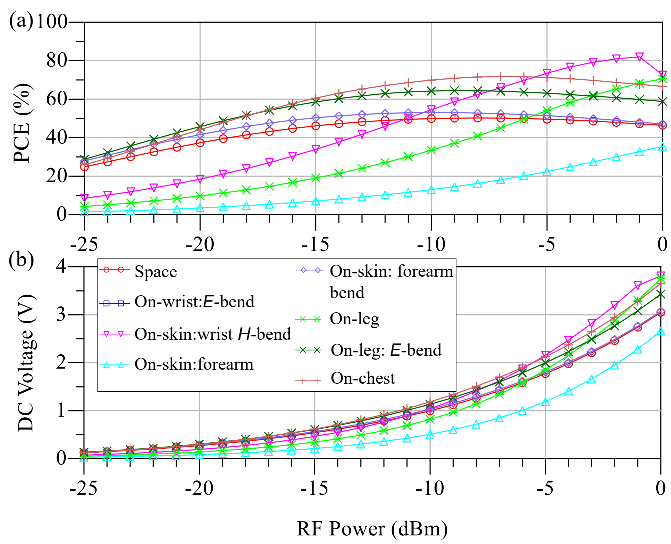

Fig. 3. The rectifier's output based on the measured Z_{in}.

Load impedance (kÝ)

Fig. 4. The rectifier's PCE at 868 MHz and 20 dBm for varying loads; legend shown in Fig. 3.

sponse, the rectifier maintains a high PCE at low power levels (in Fig. 3) indicating minimum detuning and maintaining its performance in human proximity. A load impedance and frequency sweep have been simulated at -20 dBm, to observe the variation in the rectifier's PCE in response to the different antenna Z_{in}, and are shown in Fig. 4 and 5, respectively.

The observed frequency shift in 5 correlates to the setups

Frequency (GHz)

Fig. 5. The rectifier's PCE at 20 dBm across a 20 k load for varying frequency.

where $\Im\{Z_{\text{in}}\}$ varied the most, i.e. on direct skin contact. Therefore, excluding skin absorption and body shadowing, the rectenna's PCE is expected to drop in-band due to detuning. However, the resonant frequency and optimal load impedance are mostly maintained for other measurement setups where the antenna was isolated from the body by clothing.

IV. Conclusion

In this paper, the effect of human proximity on the input impedance of a complex-conjugate textile SWIPT rectenna has been experimentally investigated. Unless the antenna is bent and pressed against the skin, minimal impedance variations are observed. Future work includes quantification of the effects of human proximity on the rectenna's gain, as well as measuring the DC output of the rectenna for different on-body positions to observe the combined impedance and radiation properties effect on the rectifier's PCE.

Acknowledgement

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