Testing and Modeling the Performance of Stretchable Screen Printed UHF RFID Tag under Strain

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***Abstract*—We characterize a passive UHF RFID tag based on a stretchable dipole antenna which is screen printed on ultra-thin polyurethane substrate with silver ink. Our results show that the change in the conductor properties due to strain is large enough to modify the electromagnetic properties of the antenna notably, yet small enough so that the tag retains high performance even under 20-% strain. By comparing the simulated and measured results, we attest a strain-dependent sheet resistance model.**

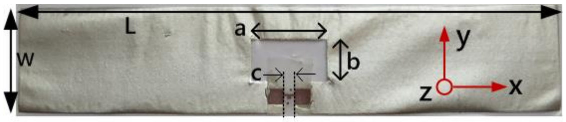
***Keywords*—screen printing; radio-frequency identification; stretchable antennas; dipole antennas; strain; sheet resistance**

I. INTRODUCTION

Numerous applications of wearable electronics, such wrist-worn activity trackers, have emerged in the consumer market. In the healthcare industry, similar devices will enable the unobtrusive monitoring of physiological parameters and hold the potential to revolutionize healthcare and wellness through remote monitoring of physiological parameters [1]. Correspondingly, methods and materials for wearable antennas have been a topic of active research during the past decade [2]. In particular, for battery-free sensing platforms, the modulation of the scattering of electromagnetic waves impinging the sensor has been found a compelling approach [2][3][4]. This is standardly used in radio-frequency identification (RFID) and currently RFID-inspired technology is being adopted in epidermal and textile-based sensor tags [3][4][5]. Here, a major challenge is minimizing obtrusiveness. To achieve this, electronics based on stretchable interconnects on ultra-thin elastomer substrates, such as thermoplastic polyurethane (TPU) which can be affixed on the skin or integrated into textiles, is a promising approach. However, it has been estimated that these devices experience strains of 15-to-20% during their lifetime [6]. Hence, in this work, we characterize a stretchable passive UHF RFID tag on TPU substrate under strains up to 20%.

II. ANALYSIS OF THE TAG’S PERFORMANCE UNDER STAIN

The studied RFID tag is based on a straight dipole antenna with embedded inductive loop matching which converts the capacitive input impedance of the dipole to inductive for complex-conjugate-matching with a capacitive RFID microchip. The antenna was screen printed from silver ink (CI-1036 from ECM) on soft and stretchable Epurex Platilon U4201 TPU with the thickness of 50 µm. The ink was pre-conditioned by hand-stirring it with a spatula in room temperature. TIC SCF-300 semi-automatic screen printer with a polyester-mesh screen (79 threads/cm, thread diameter: 55 µm, mesh opening: 69 µm, stretching angle: 22.5°) was used to deposit two layers of ink followed by curing of the pattern in 120°C for 30 minutes. NXP UCODE G2iL series RFID IC with wake-up power level of P_{ic0} = 15.8 µW was attached to the antenna using Circuit Works CW2400 conductive epoxy. In simulations, the microchip impedance (Z_C) was modelled as a parallel connection of capacitance and resistance of 0.91 pF and 2.85 kΩ, respectively. Fig. 1 shows an assembled tag and the dimensions defining the antenna. The realized dimensions measured from the manufactured antenna have been used in the simulations.



Geometrical parameter	L	W	a	b	c
Nominal value (mm)	100	20	14.3	8.13	2
Realized value (mm)	101.6	19.8	14.6	8.13	1.9

Fig. 1. The tested tag and the dimensions defining the antenna.

The electrical properties of the conductor were obtained by two-point resistance measurement of a test pattern. The mean value of sheet resistance (R_S) measured for 30 samples was 0.05 Ω/□ and it was used to model the antenna conductor in initial simulations in ANSYS HFSS v.15. As seen from Figs. 2–5, the simulation predicts the radiation efficiency (e_r) and antenna-IC power transfer efficiency (τ) of 0.86 and 0.86, respectively at 940 MHz. Assuming *EIRP* = 3.28 W, attainable free-space read range (d_{tag}) is as high as 13.1 m (Fig. 5) and 11.8 m toward the negative and positive y-axis in Fig. 1, respectively. Although both directions are in the omnidirectional plane of the dipole, the structural asymmetry introduced by the matching loop caused the directivity to be slightly higher in the direction of the positive y-axis.

Stretching of the tag along the x-axis in Fig. 1 results in elongation in the dipole antenna and is thereby expected to modify its electromagnetic properties notably. The results from simulations where R_S = 0.05 Ω/□ and L=110 mm and L=120 mm and showed that the antenna impedance was modified in such a way that the matched frequency of the tag shifted downward (Fig 3). The impact on antenna directivity (D) was found negligible and it remained at approximately constant at

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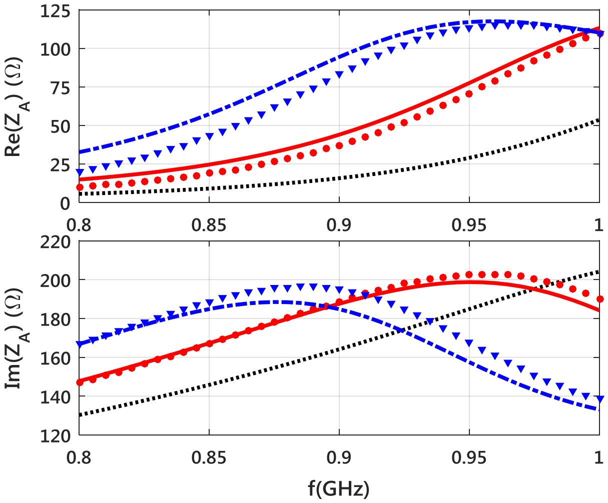

Fig. 2. Simulated antenna impedance using strain-dependent- and constant-R_S (see Fig. 4 for legend).

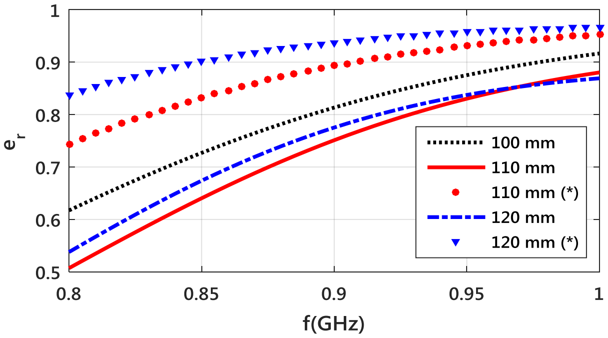

Fig. 4. Simulated antenna radiation efficiency using strain-dependent- and constant-R_S (marked with asterisk) models.

2.4 dBi (toward negat. y-axis in Fig. 1) from 800 MHz to 1 GHz. However, the increase in the electrical length of the dipole increased e_r (Fig. 4) and correspondingly, for L=120 mm, d_{tag} reached a 13.6 m at 840 MHz (Fig. 5).

In practice, however, we had observed that stretching reduced the antenna conductivity. Hence, we conducted electromechanical characterization of the printed conductor under uniaxial strain. The strain proportionality was found non-linear and it was captured well by a cubic regression: $R_S(q)=R_0(64.5269q^3+24.4836q^2+5.759q+1)$, where $R_0=0.05$ Ω/□ is the initial sheet resistance and q is the strain. The model gives R_S of 0.20 Ω/□ and 0.38 Ω/□ for the strains of $q=0.1$ and $q=0.2$, respectively. Consequently, in the simulation with the strain-dependent-R_S, e_r reduced with the strain (Fig. 4), and as seen from Fig. 3, τ was also lowered in comparison with the constant-R_S model. Overall, the reduction in d_{tag} versus strain was predicted in the simulation with strain-dependent-R_S and as seen from Fig. 5, the prediction agreed closely with the result obtained from wireless tag measurements conducted with Voyantic Tagformance system as explained in [5].

III. CONCLUSION

We characterized the performance of a stretchable passive UHF RFID tag based on a dipole antenna which was screen printed on ultra-thin TPU substrate. Our results demonstrated that accurate prediction of the impact of strain on the performance of the tag requires a strain-dependent conductor model. For this purpose, we attest a cubic regression model, which provided a close agreement with measured results. The measured result also confirmed that the studied tag maintained high read range of more than 9.5 m at 0.89 GHz for all strains up to 20% demonstrating the feasibility of stretchable screen printed antennas for radio-frequency applications.

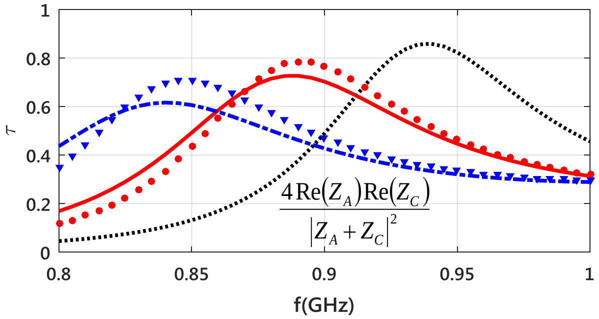

Fig. 3. Simulated antenna-IC power transfer efficiency using strain-dependent- and constant-R_S models (see Fig. 4 for legend).

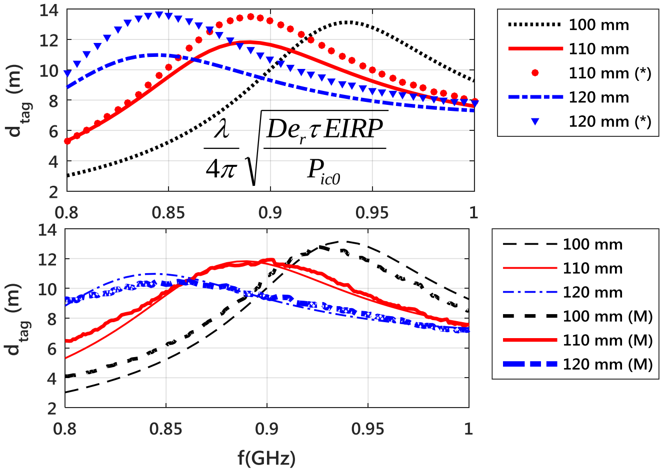

Fig. 5. Top: simulated attainable free-space read range using strain-dependent- and constant-R_S (marked with asterisk) models. Bottom: comparison of measurement and simulation with strain-dependent R_S.

REFERENCES

[1] Geng Yang, et al., “A health-IoT platform based on the integration of intelligent packaging, unobtrusive bio-sensor, and intelligent medicine box,” *IEEE Trans. Ind.l Informat.*, vol. 10, no. 4, pp. 2180–2191, 2014.

[2] P. Nepa, H. Rogier, “Wearable antennas for off-body radio links at VHF and UHF bands,” *IEEE Antennas Propag. Mag.*, vol. 57, no. 5, pp. 30–52, Oct. 2015.

[3] C. Occhiuzzi, A. Ajovalasit, M. A. Sabatino, C. Dispenza, G. Marrocco, “RFID epidermal sensor including hydrogel membranes for wound monitoring and healing,” in Dig. IEEE RFID Conf., 15-17 April, 2015, Las Vegas, NV, USA, pp. 182–188.

[4] J. C. Batchelor, O. O. Rakibet, C. V. Rumens, S. J. Holder, “Skin-mounted RFID sensing tattoos for assistive technologies,” in Dig. IEEE MTT-S IMWS-Bio, 8-10 Dec., 2014, London, UK, 3 p.

[5] Feiyuan Long, et al., “Implementation and wireless readout of passive UHF RFID strain sensor tags based on electro-textile antennas,” in European Conference on Antennas and Propagation, 12–17 Apr., 2015, Lisbon, Portugal, 5 p.

[6] B. Huyghe, H. Rogier, J. Vanfleteren, F. Axisa, “Design and manufacturing of stretchable high-frequency interconnects,” *IEEE Trans. Adv. Packag.*, vol. 31, no. 4, pp. 802–808, Nov. 2008.