Extraction of Knitted RFID Antenna Design Parameter from Transmission Line Measurements

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***Abstract*—The seamless integration of knitted antennas into electronic devices requires accurate knowledge of the electrical properties of the conductive fabrics at high frequencies. This paper shows a new method of extracting sheet resistance of knitted conductive fabric from S-parameter measurements of two-port transmission lines. The extracted sheet resistance parameter is then used to simulate knitted antennas.**

***Index Terms*—Knitted antennas, RFID (Radio Frequency Identification), sheet resistance, silver-coated nylon**

I. Introduction

Knitted antennas equipped with RFID (Radio Frequency Identification) chips have the potential to play a key role in Internet of Things (IoT)-based healthcare systems. A major drawback in the process is the lack of simulation software capable of modeling the knitted fabric at higher frequencies.

We have developed knitted RFID antennas in previous research [1–3]. The conductive fabric is made from silver-coated nylon yarns. As the yarns undergo the knitting and fabrication process, their intrinsic properties are degraded. The random nature of the delamination and exfoliation of the conductive coating over the conventional non-conductive yarns make it very challenging to develop exact 3D models of the fabric while simulating knitted antennas. Moreover, knitted yarns come with different interlocked loop patterns. As a result, the designer is forced to repeat a few trial-and-error steps to come up with a simulation model that matches the measurements.

To work towards overcoming this challenge, a complex sheet impedance ($R_s + jX_s \ \Omega/sq$) value is assigned to a 2D structure that resembles the antenna geometry. We observe that the performance of the simulated antenna is primarily dependent on the real portion, which is known as the sheet resistance (R_s). We propose a new method of extracting the sheet resistance of knitted fabrics from transmission line S-parameters. As our antenna is intended for RFID applications (902-928MHz) in the United States), we choose an operating frequency of 913MHz.

II. Extraction of RLGC Parameters

The top layer of a two-port microstrip transmission line (Fig. 1) is constructed with conductive knitted fabric, while the ground is made of copper and the substrate is FR4. Two-port S-parameters (s_{ij} ; $i, j = 1, 2$) are measured with a network analyzer. ABCD parameters are calculated from measured S-parameters (Fig. 2) using the following equations [4]:

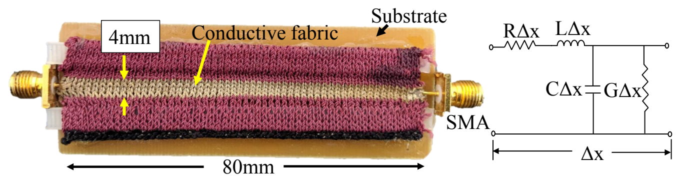

Fig. 1: (Left) Fabric transmission line and (right) the distributed circuit representation.

$$A = \frac{(1 + s_{11})(1 - s_{22}) + s_{12}s_{21}}{2s_{21}} \tag{1a}$$

$$B = Z_0 \frac{(1 + s_{11})(1 + s_{22}) - s_{12}s_{21}}{2s_{21}} \tag{1b}$$

$$C = \frac{1}{Z_0} \frac{(1 - s_{11})(1 - s_{22}) - s_{12}s_{21}}{2s_{21}} \tag{1c}$$

$$D = \frac{(1 - s_{11})(1 + s_{22}) + s_{12}s_{21}}{2s_{21}} \tag{1d}$$

where Z_0 is the normalizing impedance (50 Ω). Characteristic impedance (Z_c) and propagation constant (γ) of the transmission line can be derived from the ABCD parameters:

$$Z_c = \sqrt{\frac{B}{C}} \ ; \quad \gamma = \frac{1}{l} \cosh^{-1}(A) \tag{2}$$

where l is the length (80mm) of the transmission line. As the extraction of RLGC parameters is an ill-posed mathematical problem, we observe ripples in Z_c, while γ is free from ripples [5]. So we accept γ and reconstruct Z_c by optimization [5]. A transmission line can be represented by an equivalent electrical circuit (fig. 1) with distributed parameters (R, L, G, and C). The per unit length distributed parameters can be found:

$$R = Re(\gamma Z_c) \ ; \ L = Im(\gamma Z_c)/\omega \tag{3a}$$

$$G = Re(\gamma / Z_c) \ ; \ C = Im(\gamma / Z_c)/\omega \tag{3b}$$

where $\omega = 2\pi f$, f being the frequency of interest (913MHz). To validate the process, S-parameters are reconstructed (fig. 2) with the extracted RLGC parameters. Fig. 2 shows that the measured and reconstructed S-parameters are in good agreement. Total resistance (Ω) between the two ports of the transmission line,

$$R_{total} = (\frac{l}{1000})R \ \ ; l = 80mm$$

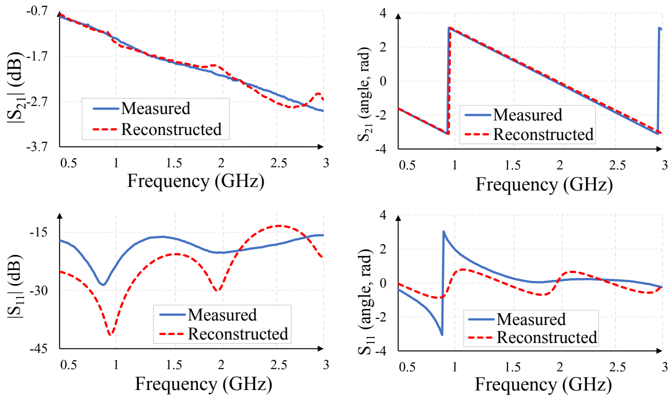

Fig. 2: Measured and reconstructed (from extracted RLGC parameters) S-parameters.

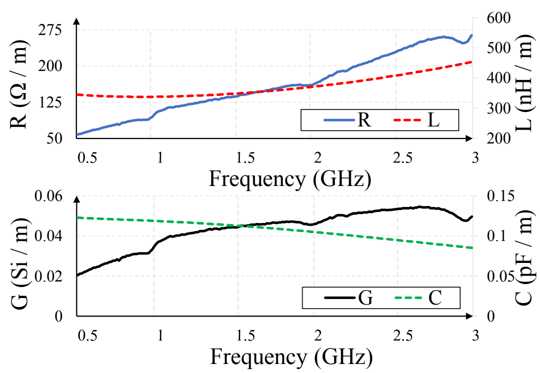

Fig. 3: Extracted RLGC parameters from S-parameters.

Total conductor loss in the transmission line is the summation of the losses occurring in the top (fabric) layer (R_{fab}), bottom (copper) layer (R_{gnd} = 0.05Ω) and radiation resistance [6, 7]:

$$R_{total} = R_{fab} + R_{gnd} + R_{rad} \tag{4}$$

Finally, sheet resistance ($R_s, \Omega/sq$) of the conductive fabric,

$$R_s = (\frac{w}{l})R_{fab} \tag{5}$$

where w is the width (4mm) of the top layer of the transmission line.

III. Results and Discussion

Fig. 3 shows the extracted RLGC parameters vs. frequency plots. The R and G-parameters increase with frequency, while L and C-parameters tend to remain stable. The R-parameter is used to determine the sheet resistance of the fabric transmission line. The calculated sheet resistance of the fabric transmission line at 913MHz is 0.4 Ω/sq.

A 2D model of the bellyband (Fig. 4) is simulated in HFSS (High Frequency Structure Simulator) with the extracted sheet resistance. The measured radiation pattern is shown in Fig. 5.

IV. Conclusion

We propose a new method of extracting ultra high-frequency (913MHz) sheet resistance of knitted antennas from S-parameter measurements of transmission lines. The sheet

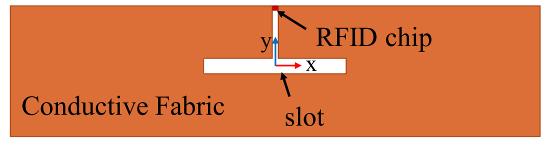

Fig. 4: HFSS model of the bellyband antenna.

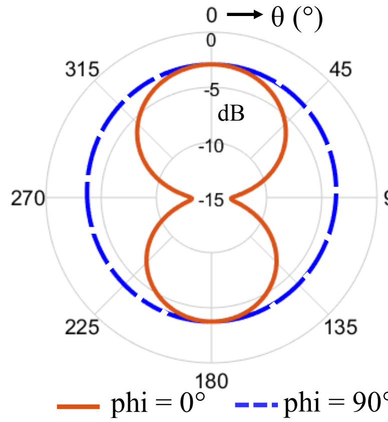

Fig. 5: Gain plot of the simulated antenna.

resistance value is crucial while simulating wearable knitted antennas. This method can also be used to characterize new materials whose high-frequency sheet resistance can not be measured directly.

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