A Bend Transducer for Backscatter RFID Sensors

Jasmin Grosinger and Joshua D. Griffin
Disney Research Pittsburgh
Pittsburgh, Pennsylvania, USA
jgrosing@nt.tuwien.ac.at, joshdgriffin@disneyresearch.com

***Abstract*—Backscatter RFID sensors are beneficial for sensing applications where small, low-maintenance sensor nodes are needed. In this paper, a transducer to monitor the curvature of a tagged object for backscatter RFID senors operating at $5.8\,\mathrm{GHz}$ is presented. It is shown, by vector network analyzer measurements, that the presented prototype, an open-circuited microstrip line resonator, changes its input impedance with bending and thus, proves feasible for integration in an RFID sensor. Analysis of the transducer's performance when integrated in a backscatter sensor is provided.**

I. Introduction

A promising communication technology for wireless sensing applications is backscatter radio frequency identification (RFID) in the ultra high frequency and microwave frequency range. Backscatter RFID in sensor networks relies on the radio communication between an RFID reader, acting as the control unit, and a multitude of passive or semi-passive RFID transponders, acting as sensor nodes. The principle of communication for transmitting information from the transponder (tag) to the reader relies on a modulated backscatter signal [1]. All power for the transmission of the sensor data is drawn from the electromagnetic field radiated by the reader. Hence, their low-power consumption makes backscatter tags appropriate for sensing applications that require small, lightweight, and low-maintenance nodes – e.g., car tire or remote health monitoring applications, as well as human-computer-interaction applications in the entertainment industry.

In this paper, a transducer to monitor the curvature of a tagged object is presented. The transducer, which changes its electrical impedance as a function of bending, can be integrated in a backscatter RFID sensor node. The transducer's impedance change then directly modulates the backscattered signal in amplitude and phase. Consequently, the RFID reader can wirelessly detect the sensor data without power consuming analog-to-digital converters or other conventional radio frequency (RF) circuitry on the backscatter sensor.

There are two promising approaches to integrate a transducer in a backscatter RFID tag. One approach is to use the tag's antenna as the transducer, denoted as an *antenna transducer*. Previous research on the integration of sensing abilities in backscatter RFID tags, without the use of additional RF circuitry, has focused on the use of antenna transducers [2]–[6]. A main advantage of such transducers is that they allow the use of off-the-shelf microchips. However, because of the change in the antenna's impedance, the power available at the chip's circuitry could be reduced [7]. This power loss impairs the system performance and can be considered a disadvantage for forward-link-limited backscatter RFID systems. The other approach is to integrate a specially-designed transducer structure in the antenna load. This is termed a *chip transducer* and has received less attention in the literature. Tentzeris and Nikolaou [8] present a chip transducer design for a chipless RFID tag, which uses a film of single-walled carbon nanotubes as the antenna load to detect toxic gas.

This work experimentally demonstrates a chip transducer prototype which changes its input impedance with bending for integration into a backscatter RFID sensor at $5.8\,\mathrm{GHz}$.

Jasmin Grosinger performed this research while a lab associate at Disney Research, Pittsburgh. She is currently a PhD student at the Institute of Telecommunications at the Vienna University of Technology, Austria.

II. Prototype and Measurement Results

Resonant structures, e.g. patch antennas, show a shift in resonant frequency when they are bent along the dimension determining their resonance [9]–[11]. Thus, an open-circuited microstrip line resonator, which is bent in the direction of its transmission line, is explored to act as a chip transducer. The realized prototype can be seen in Fig. 1. The structure is made of single-sided, copper-clad flexible laminate, DuPont's Pyralux FR9150 [12]. Its thickness is $0.127\,\mathrm{mm}$ and the material parameters have been provided by the manufacturer. The microstrip line is made of copper tape applied to the un-clad side of the laminate and has a length of $55\,\mathrm{mm}$ which has been chosen to realize a high backscatter transducer performance at $5.8\,\mathrm{GHz}$. Its groundplane size is $30\,\mathrm{mm} \times 80\,\mathrm{mm}$.

The transducer's input impedance was investigated for three exemplary bending states defined by their bending radius, R_{Bend}, i.e., the radius of the cylinder around which the transducer was bent. $R_{\text{Bend}} = \infty$ represents the planar case, while $R_{\text{Bend}} = 84.1\,\mathrm{mm}$ and $R_{\text{Bend}} = 21.1\,\mathrm{mm}$ represent two bending states with increasing curvature. Polyvinyl chloride (PVC) sheets and pipes were used to realize the different bending states. The transducer's input impedance versus bending was measured by means of a vector network analyzer (VNA), Agilent's E5071C. An SMA connector was used to feed the structure and the VNA's calibration was adjusted accordingly. The relatively large dimensions of the prototype, which operates at $5.8\,\mathrm{GHz}$, were chosen to allow the input impedance measurement using the VNA. It was found that the measurement setup is only suitable for longer resonator lengths because the behavior of the resonant frequencies with

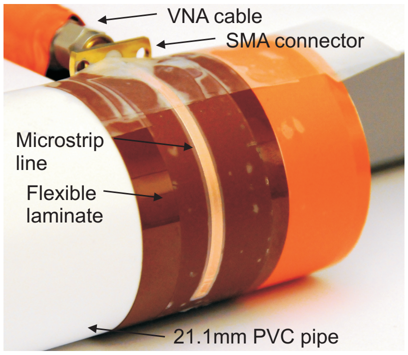

Fig. 1. The transducer prototype in the input impedance measurement setup.

bending for short resonators seemed to be impaired by the rigidness of the attached SMA connector.

Fig. 2 shows the mean values of the structure's input impedance versus frequency and bending state. R is the real part and X is the imaginary part of the transducer's input impedance, $Z = R + jX$. The mean value was calculated from five different measurements in which the prototype was repeatedly attached to the PVC material and connected to the VNA. These repeatability measurements were done to verify the accuracy of the input impedance measurement. It can be seen from Fig. 2 that the structure's resonant frequency shifts to lower frequencies when it was bent. This shift is also found in simulation. Another prototype with the same dimensions was measured and, although the resonant frequencies differed because of manufacturing variances, it showed the same resonant frequency trend as the first.

III. System Performance and Future Work

It can be seen from Fig. 2 that the investigated transducer prototype shows the desired change in its input impedance with bending. The transducer, when integrated in a backscatter RFID tag, will be operated in the resonator's capacitive range, at 5.8 GHz, to realize a strong backscatter signal. Tab. I lists the realized impedance values at this frequency. Operating the resonator at 5.8 GHz, not at its self-resonance, reduces unintentional radiation from the structure, as shown by simulations.

The backscatter sensor performs best when there is a large phase change $\Delta\varphi$ in the backscattered signals with changing bend radius and when the modulation efficiency η [1] is high. Calculations show, that the transducer shows good performance in the backscatter sensor, as presented in Tab. I. To calculate the modulation efficiency of the backscattered signal, the transducer's input impedance was used as the reflecting impedance and a perfectly matched antenna load was assumed for the absorbing impedance.

This paper has shown that an open-circuited microstrip resonator can be used to sense bend with a backscatter sensor. Future work includes integrating the transducer into a backscatter sensor and measuring its performance.

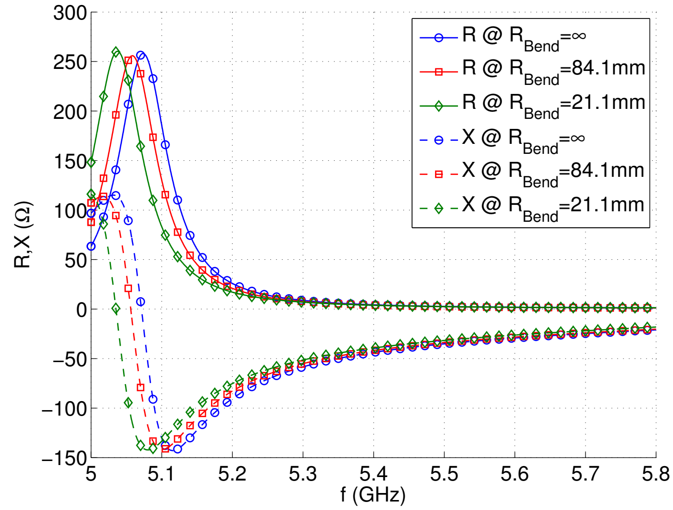

Fig. 2. Mean of the real part R and the imaginary part X of the measured transducer input impedance versus frequency f and bending states.

TABLE I
Transducer impedance Z; phase difference $\Delta\varphi$ (reference state: $R_{\text{Bend}} = \infty$) and modulation efficiency η of the backscattered signal at $f = 5.8\,\text{GHz}$ versus bending states.

R_{Bend} (mm)	Z (Ω)	$\Delta\varphi$ (°)	η (%)
∞	$1.21 - j21$	–	10
84.1	$1.15 - j20.3$	16.5	11
21.1	$1.37 - j18.1$	60.2	11

References

[1] J.-P. Curty, M. Declercq, C. Dehollain, and N. Joehl, *Design and Optimization of Passive UHF RFID Systems*. New York: Springer Science+Business Media, LLC, 2007.

[2] S. Capdevila, L. Jofre, J. Romeu, and J. Bolomey, "Passive RFID based sensing," in *Proc. IEEE International Conference on RFID-Technologies and Applications*, 2011.

[3] R. Bhattacharyya, C. Floerkemeier, and S. Sarma, "Low-cost, ubiquitous RFID-tag-antenna-based sensing," *Proc. IEEE*, vol. 98, no. 9, 2010.

[4] J. Siden, X. Zeng, T. Unander, A. Koptyug, and H.-E. Nilsson, "Remote moisture sensing utilizing ordinary RFID tags," in *Proc. IEEE Sensors*, 2007.

[5] S. Caizzone, C. Occhiuzzi, and G. Marrocco, "Multi-chip RFID antenna integrating shape-memory alloys for detection of thermal thresholds," *IEEE Trans. Antennas Propag.*, vol. 59, no. 7, 2011.

[6] C. Occhiuzzi, A. Rida, G. Marrocco, and M. Tentzeris, "RFID passive gas sensor integrating carbon nanotube," *IEEE Trans. Microw. Theory Tech.*, vol. 59, no. 10, 2011.

[7] K. Rao, P. Nikitin, and S. Lam, "Antenna design for UHF RFID tags: A review and a practical application," *IEEE Trans. Antennas Propag.*, vol. 53, no. 12, 2005.

[8] M. Tentzeris and S. Nikolaou, "RFID-enabled ultrasensitive wireless sensors utilizing inkjet-printed antennas and carbon nanotubes for gas detection applications," in *Proc. International Conference on Microwaves, Communications, Antennas and Electronics Systems*, 2009.

[9] K.-L. Wong, *Design of Nonplanar Microstrip Antennas and Transmission Lines*. New York: John Wiley & Sons, Inc., 1999.

[10] P. Salonen and Y. Rahmat-Samii, "Textile antennas: Effects of antenna bending on input matching and impedance bandwidth," *IEEE Aerosp. Electron. Syst. Mag.*, vol. 22, no. 3, 2007.

[11] S. Koulouridis, G. Kiziltas, Y. Zhou, D. Hansford, and J. Volakis, "Polymer-ceramic composites for microwave applications: Fabrication and performance assessment," *IEEE Trans. Microw. Theory Tech.*, vol. 54, no. 12, 2006.

[12] DuPont. (2011, December) DuPont Pyralux FR Copper-Clad Laminates. [Online]. Available: http://www2.dupont.com/