Passive Displacement Sensing using Backscatter RFID with Multiple Loads

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Summary

Backscatter radio frequency (RF) tags and radio frequency identification (RFID) tags can be used to create wireless sensors that do not require a battery by using the tag antenna's electrical load as a transducer. This paper presents such a backscatter sensor system operating in the 5.8 GHz unlicensed frequency band that wirelessly senses displacement between one and five millimeters. The system senses the variable impedance of a covered, open-circuit microstrip line and uses two fixed antenna load impedances to remove the effects of the radio channel. The primary contribution of this paper is a demonstration of the wireless sensing system in which the binary position of a human finger (e.g., "bent" or "straight") is measured using a passive transducer for wireless human-computer-interaction (HCI) applications.

Motivation

In many sensing applications, including HCI applications such as wireless game controllers or wearable motion capture systems, it is desirable to use sensors that can be read wirelessly and do not require a battery. Backscatter RF tags are attractive for such applications as they provide extremely low-power wireless communication and sensing capabilities. Two basic approaches to backscatter RF tag sensing are possible. The first is to use the tag's antenna as the transducer[1], and the second is to use the tag antenna's load impedance as the transducer (i.e., a load transducer)[2,3,4]. A load transducer allows the tag antenna's performance to remain constant, keeping the tag's power link to the reader optimal. In this paper, a 5.8 GHz, backscatter sensor system, diagrammed in Fig. 1, is presented and proven capable of measuring displacement using a load transducer. The load transducer is a covered microstrip transmission line with an open-circuit termination, shown in Fig. 2a. The cover is placed over the microstrip line and the distance between them varied resulting in a change in the load transducer input impedance Z_v. Two additional fixed loads allow the impedance or change in impedance (i.e., relative impedance) of the transducer to be measured without knowledge of the radio channel. It is shown that it is necessary to use RF tag sensors with at least three loads[4] even if only relative sensor data is to be collected. The sensor is to be integrated into a glove and used to passively sense the position of a human finger, illustrated in Fig. 2b.

Results

The sensor system was demonstrated using a prototype backscatter tag and load transducer to measure the position of a human finger. The cover for the open-circuit microstrip line was attached to the index finger, as shown in Fig. 3a, and the microstrip line was placed on the upper side of the hand extending beyond the metacarpophalangeal joint of the index finger. The input impedance Z_v varied with the distance between the cover and microstrip line and was measured wirelessly using the system diagrammed in Fig. 1. Although only relative Z_v measurements were required, determining the absolute Z_v is trivial when using multiple loads with a known tag antenna impedance and, therefore, absolute measurements are reported in Fig. 3b. The change in the transducer's input impedance was adequate to distinguish between the finger being "bent" or "straight" and can be measured at multiple distances between the tag and reader. A DC supply was used to power the microwave switches in this prototype; however, since the load transducer is a passive device, the sensor tag can be operated without a DC supply by using a charge pump to harvest energy from the electromagnetic wave incident on the RF tag antenna.

[1]R. Bhattacharyya, C. Floerkemeier, S. Sarma, "Low-Cost, Ubiquitous RFID-Tag-Antenna-Based Sensing," *Proceedings of the IEEE*, vol. 98, no. 9, pp. 1593–1600, Sept. 2010.

[2]C. Occhiuzzi, A. Rida, G. Marrocco, M. Tentzeris, "RFID Passive Gas Sensor Integrating Carbon Nanotubes" *IEEE Transactions on Microwave Theory and Techniques*, vol. 59, no. 10, pp. 2674–2684, Oct. 2011.

[3]J. Grosinger and J. D. Griffin,"A Bend Transducer for Backscatter RFID Sensors" *2012 IEEE Antennas and Propagation Society International Symposium (APSURSI)*, pp. 1 - 2, July 2012.

[4]S. Capdevila, L. Jofre, J. Romeu, and J. Bolomey, "Multi-loaded Modulated Scatterer Technique for Sensing Applications," *IEEE Transactions on Instrumentation and Measurement*, vol. 62, no. 4, pp. 794–805, 2013.

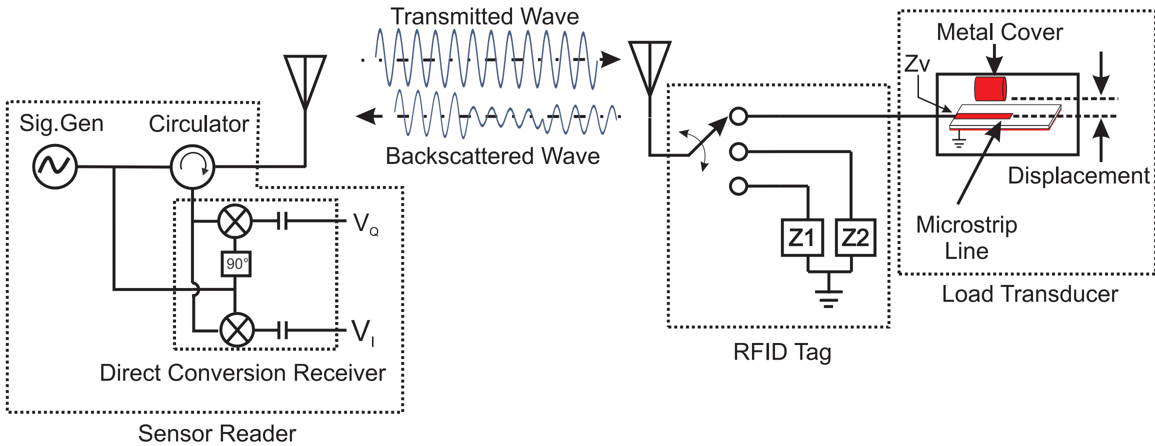
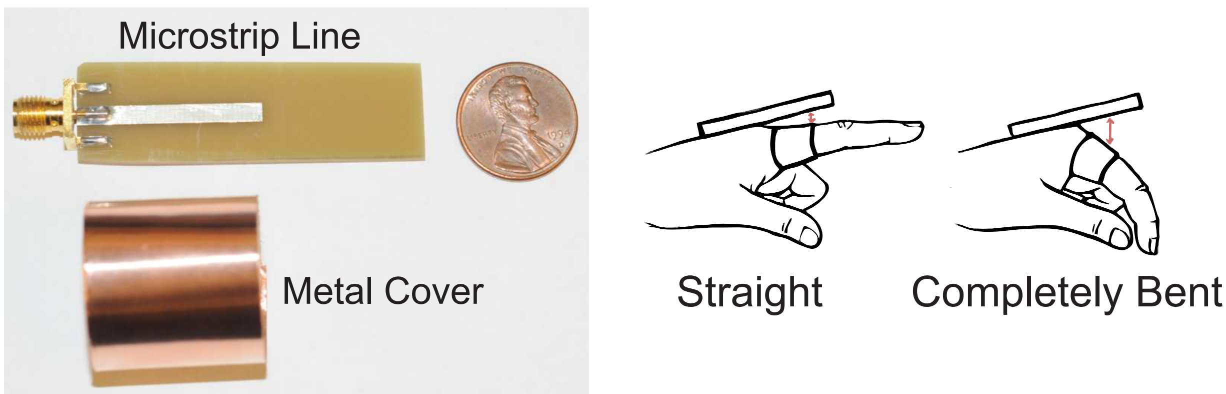
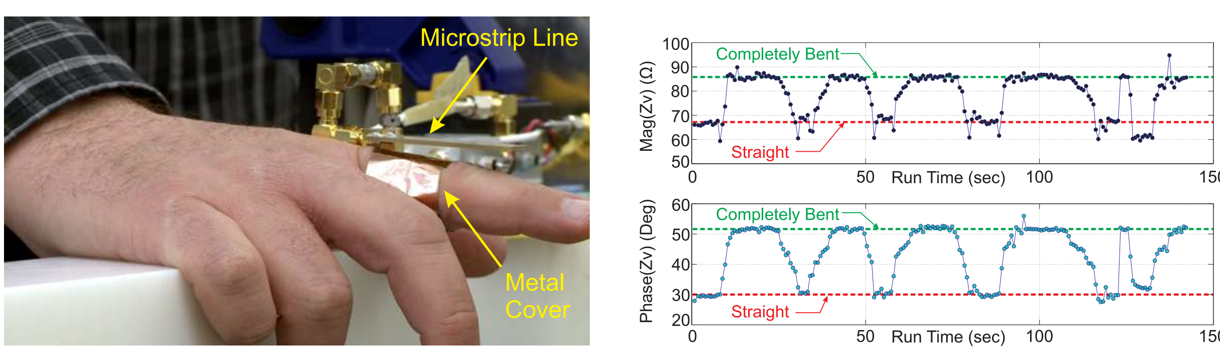


Fig. 1. A backscatter sensing system showing the 5.8 GHz sensor reader and a multi-state, backscatter RF tag with a load transducer to sense displacement. Two fixed load impedances (Z_1 and Z_2) are used to remove radio channel effects from the measurement of the unknown load transducer input impedance Z_v, which varies with the distance (i.e., displacement) between the microstrip transmission line and the metal cover.



(a) (b)

Fig. 2. The load transducer prototype showing (a) the components of the load transducer and (b) how it is used to sense the position of a human finger. The microstrip transmission line with an open-circuit termination is placed on the upper side of the hand extending beyond the metacarpophalangeal joint of the index finger and the metal cover is wrapped around the index finger. The input impedance Z_v of the load transducer varies with the distance between the metal cover and the microstrip line.



(a) (b)

Fig. 3. A demonstration of the sensor system showing (a) a photo of the load transducer fitted on the index finger and (b) the wirelessly measured magnitude and phase of the load transducer input impedance Z_v as the finger is moved between the "completely bent" and "straight" positions.