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A Monopole-Coupled RFID Sensor For Pervasive Soil Moisture Monitoring

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***Abstract*—We present the design of an RFID-based passive sensor for pervasive soil moisture monitoring. Permittivity of soil changes with variations in moisture content causing a controlled change in the signal response of an RFID tag. We demonstrate that the passive sensor can reliably detect soil moisture content over a read distance of at least 0.8 m. Future research directions and prospective design improvements are also discussed.**

I. INTRODUCTION

Passive RFID has gained much traction as a sensor in addition to an object identification technology for high volume asset tracking. Passive RFID tags can be manufactured in high volumes at 7-15 US cents per tag [1]. With an increasing demand of passive wireless sensors with capabilities much more than bare identification, RFID offers a cost effective solution in the shape of tag-antenna based sensors. We are thus presented with a potentially ideal wireless communication infrastructure for pervasive sensing.

Researchers have successfully developed pervasive sensors to measure parameters such as humidity and temperature using ordinary RFID tags [2]–[4]. In these sensors, changes in the parameter of interest are related to a change in the backscattered signal response.

Immense need of pervasive field moisture sensing is identified in agriculture. Crop growth is particularly sensitive to soil moisture content in the first few months of cultivation [5]. Furthermore due to differences in topology and drainage conditions, soil moisture can vary significantly across a field [6]. We propose the design of a passive RFID based sensor that can record a change in soil moisture content. As the soil moisture changes, it manifests itself as a change in the backscattered signal strength, which can be used for remote moisture sensing. In the following sections, we discuss the sensor design and the results of preliminary experimentation.

II. SENSOR DESIGN

The working concept of the sensor is illustrated in Fig 1. The signal response of the tag is dependent upon several factors such as the reader and tag gains, G_{tag} and G_{reader}, the reader transmitting power, P_{TX}, and how well matched the antenna impedance is to the chip impedance — a parameter measured by the power transfer coefficient τ. The sensor is designed so that the tag's antenna is connected to a monopole probe. When the probe is inserted into dry soil, the antenna is well matched to the tag RFIC and thus the tag-sensor responds with a strong signal.

However, if the soil is wet, it changes the probe impedance as seen in Fig 1. This manifests itself as a change in τ and G_{tag}. The increase in soil moisture content can thus be related to a drop in the backscattered signal strength. In the following section, we discuss the design of the monopole probe, experimental setup and the preliminary results.

III. MEASUREMENTS AND RESULTS

The input impedance (Z_{in}) of a monopole probe depends on the ϵ_r of the material it is inserted into. Approximate length of the monopole probe, optimized for performance at 915 MHz, is determined using the analytical model developed by Wu [7]. The monopole probe is immersed in sand and connected to a VNA as shown in Fig.10 of [8]. Z_{in} of the probe is measured for dry sand, and for different levels of moisture in it. The real part of Z_{in} changes from 150Ω to 9Ω when 20mL (moisture $\approx 7\%$) of water is added to the sand as shown in Fig. 3. However, the variation significantly decreases with further addition of water (moisture $\approx 14\%$). It was observed that an increaase in moisture level causes a comparatively uniform change in the imaginary part of Z_{in} as shown in Fig. 3.

The probe is connected to the RF tag as seen in Fig 2. The tag antenna is designed so that it is best tuned to the probe's impedance in the dry state. The experimental setup comprised an Impinj RFID reader to read two tags simultaneously; the

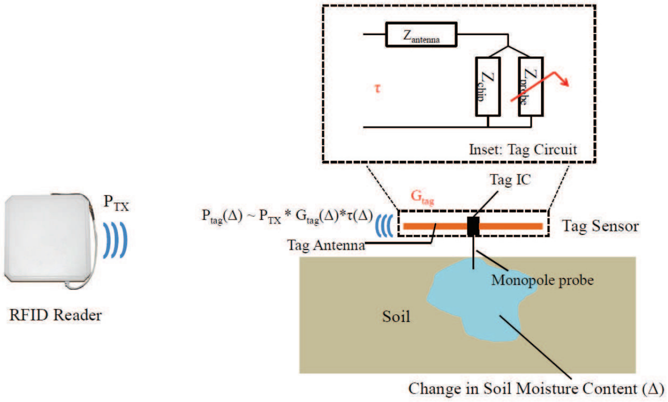

Fig. 1. The tag antenna-based sensing principle for soil moisture monitoring

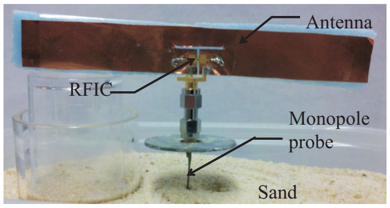

Fig. 2. Monopole probe connected to an RFID tag

sensor tag, and the reference tag. The change in soil ϵ_r due to a change in the moisture level is reflected in the strength of the signal backscattered form the sensor tag. Starting with the dry sand, we gradually increased the water content of the soil and observed the backscattered signal strength. The reader was placed at a distance of 0.8 m from the RF tags. For dry sand, the response from the sensor tag was measured to be approximately -32.5dBm. Adding 100mL of water resulted in an improvement in the tag response as shown in Fig. 4. Owing to inaccuracies in the T-slot antenna cutting and RFIC soldering, the slightly moist soil provided a better impedance match and thus causing an increase in the backscattered signal strength. Adding another 60mL of water caused the RSSI to drop to -36.5dBm, and another 40mL of water turned the tag off (-55dBm indicates no response form the sensor tag). The tag responded again after the sand was allowed to dry for approximately 7 hours. Without adding more water, sensor tag response was recorded for around 40 hours. The sand continued to dry causing the ϵ_r of sand and the input impedance of the sensor probe to gradually get close to the initial values of dry state. This resulted in a gradual increase in the RSSI values of the signal backscattered from the sensor tag as shown in Fig. 4. These results clearly indicate the possibility of sensing the moisture level of sand over given time period with the proposed passive sensor.

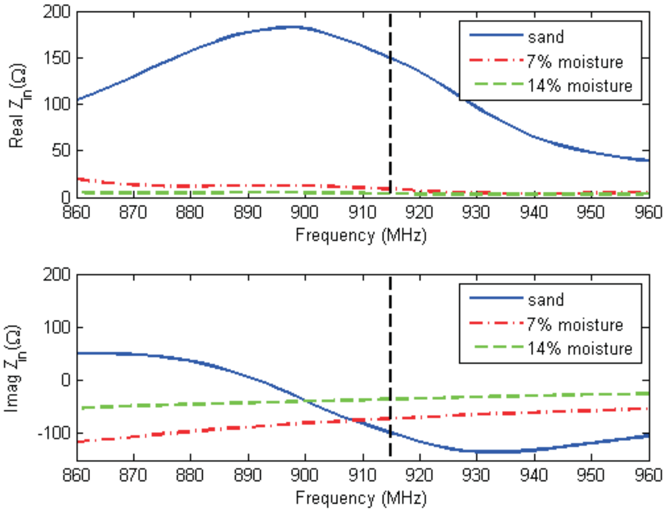

Fig. 3. Real and imaginary part of Z_{probe} measured using a network analyzer for the monopole probe immersed in dry sand and moist sand

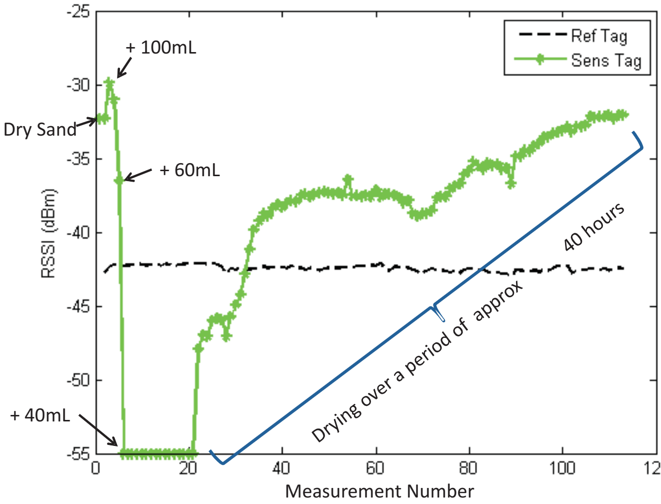

Fig. 4. Strength of the signal backscattered from the sensor tag inserted in sand. No response is indicated as -55dBm

IV. DISCUSSION AND FUTURE WORK

The design feasibility presented in this paper leads to several open avenues for future work. First, we intend to improve the sensor precision and read range. Second, it is important to examine the performance of the sensor when inserted into different types of soil with varying degrees of compaction. Finally, it would be interesting to observe the effect of ion concentration, such as nitrates and phosphates, on the proposed sensor performance to see if this concept could be extended to nutrient sensing as well.

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