# SIMULTANEOUS MOISTURE AND SALINITY MONITORING IN SOILS USING SPLIT RING RESONATOR(SRR) BASED SCANNING FREQUENCY TRANSMITTORY(SFT)

*Sunghyun Hwang[1*], William N. Carr[2] and Yong-Kyu Yoon[1]*
[1]Department of electrical and computer engineering, University of Florida, Gainesville, FL, USA
[2]NeptuneSensor, Gainesville, FL, USA

## ABSTRACT

A new type of impedance spectrometry, the so called scanning frequency transmittory (SFT), is introduced for moisture and salinity monitoring in soils using a single split-ring resonator (SRR) sensor. The system concept has been experimentally verified using a passive SRR antenna-resonator with a vector network analyzer (VNA) and an ultra-high frequency (UHF) radio-frequency identification (RFID) tag readout. The demonstrated sensing system enables simultaneous monitoring of moisture and salinity in a simple configuration with remote readout, battery-free sensing, and cost-effectiveness advantageous for a practical implementation toward the Internet of Agriculture Things (IoAT).

## KEYWORDS

Scanning frequency transmittory (SFT), split-ring resonator (SRR), radio-frequency identification (RFID), internet of agriculture things (IoAT), sub-soil monitoring, wireless sensing.

## INTRODUCTION

As the world's population continues to grow, food production must be increased to meet the need for an estimated 9.8B world population by 2050. Moisture in soils is essential for plant growth. With global warming, the sea level increases, and the coastal areas are more vulnerable to the high salinity levels in soils affecting plant growth [1]. Simultaneous measurement of the moisture and salinity levels and controlling these levels would have a significant contribution to maximizing the crop harvests in agriculture. Previous studies have shown various ways to detect moisture levels such as Frequency Domain Reflectometry and Time Domain Reflectometry [2]-[3], which often are limited with moisture measurements only, and require complex electronic systems and high ownership costs.

In this work, we introduce a new type of impedance spectrometry that is named a scanning frequency transmittory (SFT) system using a split-ring resonator (SRR) antenna for simultaneous moisture and salinity monitoring in soils. The SFT system concept has been experimentally verified using a passive SRR antenna with a vector network analyzer (E5071C, Agilent Technologies Inc.) and wireless RFID reader-based test setup. A complementary split-ring resonator (CSRR) loaded transmission line and an SRR antenna are simulated and fabricated for experiments.

## DESCRIPTION OF THE NEW SYSTEM

The SFT sensor comprises a metamaterial SRR antenna providing sensing at UHF frequencies. A schematic for the SRR SFT moisture and salinity sensing system is shown in Fig. 1. When the moisture concentration in soils changes, the air pores in the soils are replaced by water with a higher dielectric constant than that of air, resulting in an increased effective dielectric constant, thus downshifting the resonant frequency. Meantime, the salinity level in the water does not affect its dielectric constant but its conductivity and thus the loss factor and the Q-factor [4]. The effect of loss tangent and permittivity on the sub-soil is simulated with an SRR antenna operating at 920 MHz using a High-Frequency Structural Simulator (HFSS) as shown in Fig. 3. The loss tangent did not highly impact the change of the resonant frequency while impacting the Q-factor, i.e. the peak value. Meantime, the change in permittivity value causes the resonant frequency to shift [5].

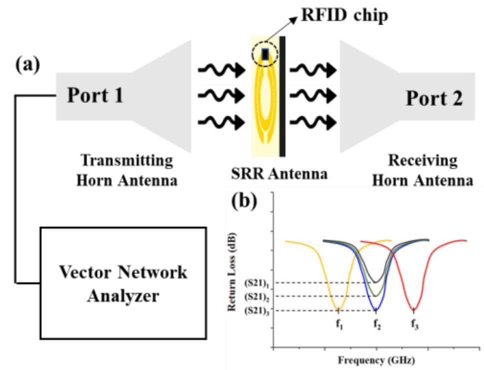


*Figure 1. Scanning frequency transmittory (SFT) system: (a) A schematic for the concept, (b) $f_1$, $f_2$, and $f_3$ indicate different moisture levels. $(S21)_1$, $(S21)_2$, and $(S21)_3$ do different salinity levels.*

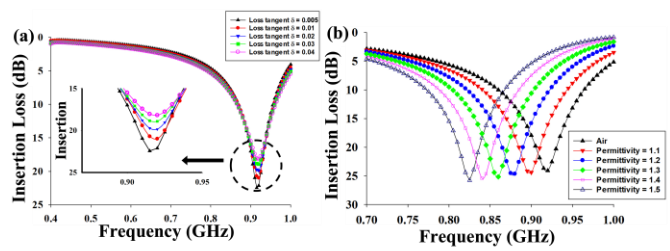


*Figure 2. Simulated insertion loss (a) with different loss tangent δ and (b) with different permittivity.*

## SENSOR DESIGN AND FABRICATION

The SRR antenna is designed using HFSS for a sensor node as shown in Fig. 3. The antenna has a radius of 28 mm and an overall size of 60 × 60 mm$^2$. The antenna operates at 920 MHz in free space. The SRR structure shows several advantages as an RFID tag antenna such as low profile, compact size, long read range, and mitigation of blind spot.

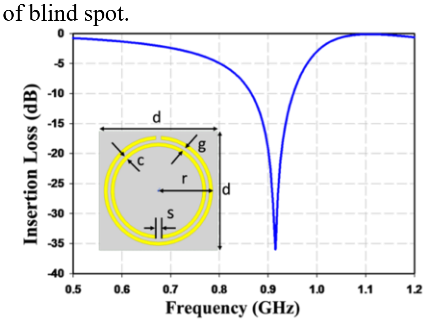


*Figure 3. Simulation result of the SRR antenna and schematic configuration of the SRR (inset), where d = 60 mm, r = 28 mm, g = 2.2 mm, s =2.8 mm and c = 2 mm.*

As a variation of resonator type SFT, a CSRR loaded transmission line is designed, simulated, and fabricated to verify the shift of resonant frequency surrounding the sensor. Fig. 4. shows fabricated sensors: (a) SRR sensing antenna integrated with an Alien Higgs3 RFID chip and (b) CSRR loaded transmission line. The SRR antenna is designed as 2.5 times bigger than the CSRR loaded transmission line, showing the improved efficiency and gain of the antenna at the same frequency (915 MHz), which enables longer and wider range detection as a sensor node. The antenna and transmission line are fabricated using milling machine on a printed circuit board (Rogers 4350B, Rogers Inc.) with a dielectric constant of 3.44 and a loss tangent of 0.004.

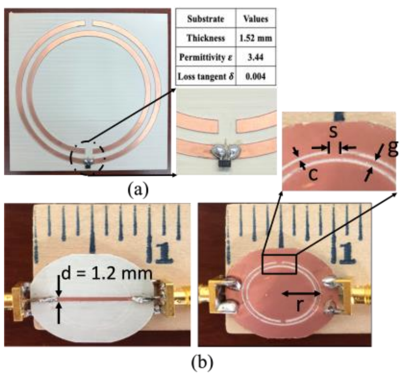


*Figure 4. Images of fabricated sensors: (a) SRR sensing antenna and a close-up view of the Alien Higgs 3 RFID chip with a table showing the substrate properties, (b) Top view and bottom view of a 1-inch sized CSRR loaded transmission line, where r = 8.4 mm, g = 1.1 mm, s = 2.2 mm and c = 0.8 mm.*

## EXPERIMENT SETUP AND RESULTS

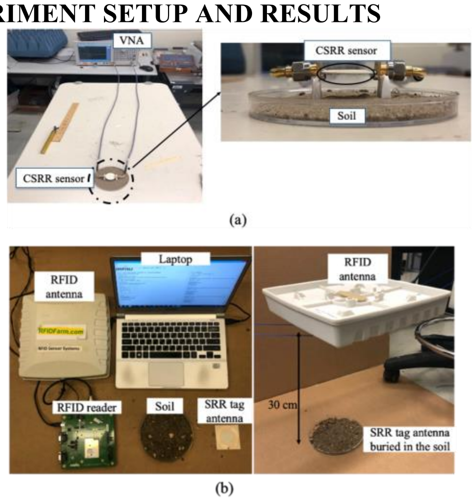


*Figure 5. (a) Vector Network Analyzer based wired test setup, (b) Wireless RFID reader based test setup.*

In this work, two types of sensing tests have been performed as shown in Fig. 5. First, the VNA has been utilized for s-parameter measurement in a planned frequency range for the proof of concept (Fig. 5a). Second, wireless remote readout experiments have been performed using a standard RFID reader and a passive RFID tag (Fig. 5b). The complete sensing system comprises a passive RFID tag loaded SRR and an Impinj RS2000 interrogator. For this test, the RFID readout antenna has been fixed at an altitude of 30 cm above the soil surface. The designed SRR antenna has been buried in the soils at 1.5 cm depth with various moisture and salinity levels.

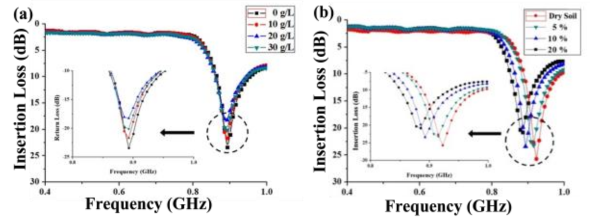


*Figure 6. Measured insertion loss (a) at 10 wt% water with different salinity levels and (b) at different moisture levels.*

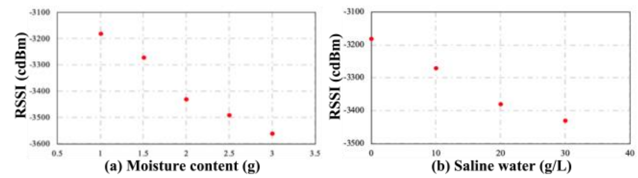


*Figure 7. Measured RSSI (a) at different moisture levels and (b) at a different salinity level in 10 wt% moisturized soils.*

Fig. 6a and 6b show the salinity and moisture-dependent s-parameters of the VNA-based setup, respectively. The salinity level shows little change in the center frequency of the antenna. However, the different moisture level has made an obvious change in the center frequency of the sensor as expected. Fig. 7 shows received signal strength indicator (RSSI) results (equivalent to S21), which are obtained from the wireless RFID reader. The decrease in RSSI value is due to the shift of resonant frequency at the different moisture content (Fig. 7a) and is due to the decrease in Q-factor at different saline content (Fig. 7b) as proved in the first experiment. Further studies should include the resonant frequency information when determining the effect of moisture and salinity content from a single RSSI value.

## CONCLUSION

This work demonstrates a new type of impedance spectrometry that is called SFT using an SRR antenna for the simultaneous monitoring of moisture and salinity level in the soils. It is expected that the introduced SFT system will provide a wireless, battery-free sensor node, cost-effective monitoring system for simultaneous moisture and salinity sensing.

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## CONTACT


*SH. Hwang, tel: +1-352-278-8325; sunghyun.hwang@ufl.edu