Moisture content sensor detecting difference of mutual coupling magnitude between parallel and perpendicular dipole antennas

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Abstract This paper presents a non-invasive moisture content sensor. It operated at 245 MHz by detecting difference of mutual coupling magnitude between parallel and perpendicular meander line dipole antennas. A power function is used for fast approximation of moisture content from the measured mutual coupling result. This sensor is essential to the effective irrigation system.

Keyword Soil moisture content sensor, mutual coupling, meander line dipole

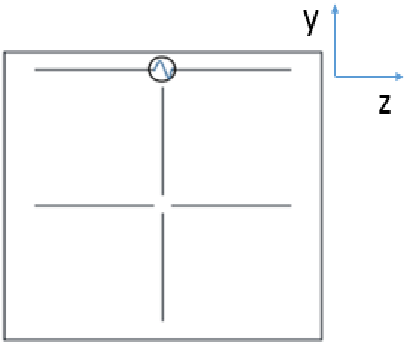
1. INTRODUCTION

Soil moisture content is important to the yield of plantation and it is necessary to know accurately. Many research have been conducted to develop soil moisture content sensor, e.g. [1] using capacitance measurement but a sensor must be invaded to the soil. The work in [2] is a non-invasive technique which adopted ultra-wideband radar. For a large area, a sensor that can measure in real time is desirable. It must provide fast results and do not need to plunge into the soil. While using only one antenna is effective [3], it needs a costly complex measurement. The work in [4] was developed for in-situ monitoring moisture content of paddy without using a directional coupler by measuring coupled signals from parallel and perpendicular dipole antennas. For the dielectric properties determination at the surface without using a directional coupler that reduces sensitivity of the system, the coupled signals from parallel and perpendicular dipole antennas can be applied.

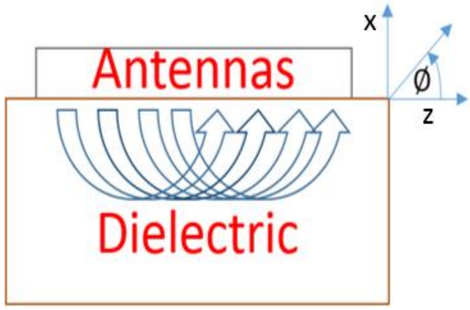
2. PRINCIPLE

The work in [4] was proposed for plunging the sensor in the material of interest. The geometry of the sensor, which one dipole antenna was used for transmitting signal and the other two dipole antennas were used for receiving coupled signals, is shown in Fig.1 (a). Note that one was for parallel polarization whereas the other one was for perpendicular polarization.

For convenience in measuring large amount of data in large area, this work placed the sensor on the surface of the material of interest which is soil. The mutual coupling for the full-space is as shown in [4]. For the half-space representing a sensor placed on the surface of the material as in Fig.1 (b), the region of interest is divided into two parts; free space and dielectric (here is soil). The self impedance (Z_{11}) and mutual impedance (Z_{21}) for parallel and perpendicular polarizations are presented as in (1) and (2) where ϕ represents the angle surrounding the antennas in two mediums. ε_0 and ε_d are dielectric properties of free space and dielectric of interest, respectively.



(a) Top view



(b) Side view

Fig.1 Geometry of the problem.

$$Z_{11} = (R_{11} + jX_{11})\frac{\int_0^\pi \varepsilon_0 d\phi + \int_\pi^{2\pi} \varepsilon_0 \varepsilon_d d\phi}{2\pi \varepsilon_0 \varepsilon_d} \quad (1)$$

$$Z_{21} = (R_{21} + jX_{21})\frac{\int_0^\pi \varepsilon_0 d\phi + \int_\pi^{2\pi} \varepsilon_0 \varepsilon_d d\phi}{2\pi \varepsilon_0 \varepsilon_d} \quad (2)$$

R_{11}, X_{11}, R_{21}, and X_{21} are elaborated in [4].

Once Z_{11} and Z_{21} are obtained, mutual coupling is calculated from |S21|.

$$|S_{21}| = \left|\left(\frac{2(Z_0 Z_{21})}{(Z_{11}+Z_0)^2-(Z_{21})^2}\right)\right| \quad (3)$$

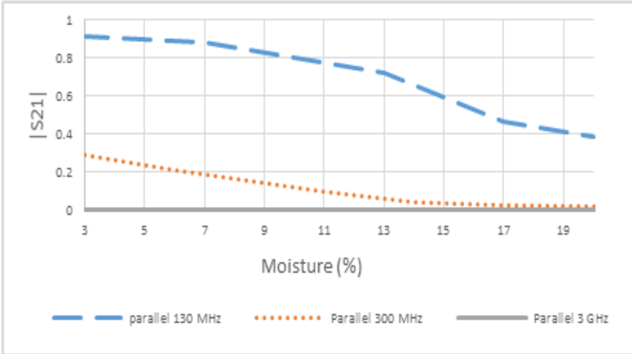
Consequently, |S21| from [4] is multiplied by $\frac{1+\varepsilon_d}{2\varepsilon_d}$.

3. CALCULATION RESULTS

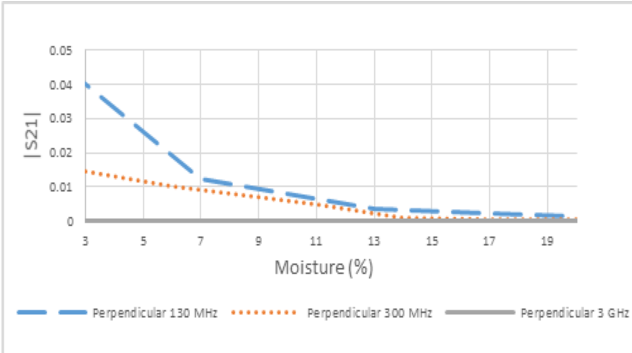
By using the data of soil from [5] and the length of the antennas are $\frac{\lambda_0}{3}$ at the operating frequencies, the mutual coupling in half-space consisting of air and soil are calculated. Fig.2 (a) and (b) show mutual coupling of parallel and perpendicular polarizations, respectively, for different moisture content of soil. It is relevant that mutual coupling decreases as moisture content increases as in case of full-space. However, it has higher values. In addition, |S21| for parallel polarization coupling is higher than that for perpendicular counterpart in the order of 20 times. Fig.2 also shows that mutual coupling for lower frequency, i.e. 130 MHz is higher than those for 300 MHz and 3 GHz. Hence, lower frequency is more suitable for sensing moisture content of soil than the higher frequency one.

In order to achieve low cost sensor, the frequency in UHF band may be suitable due to sufficiently high mutual coupling and the size of the antenna is not too large. Fig.3 shows |S21| for different moisture content of soil at 300 MHz.

The dashed line represents mutual coupling of parallel polarization which exponentially decays as moisture content increases. In practice, we need to find moisture content from the measured mutual coupling quickly. Hence, mutual coupling is approximated by exponential function $0.4773e^{-0.167x}$ as shown by dotted line in Fig.3. Since perpendicular polarized coupling has lower value than the parallel ones, the different values of the parallel and perpendicular polarizations are close to the approximated values and can provide the more accurate results. The dashed-dotted line presents the difference of two couplings.



(a)



(b)

Fig.2 Mutual coupling versus soil moisture content for different frequencies.
(a)Parallel polarization
(b)Perpendicular Polarization

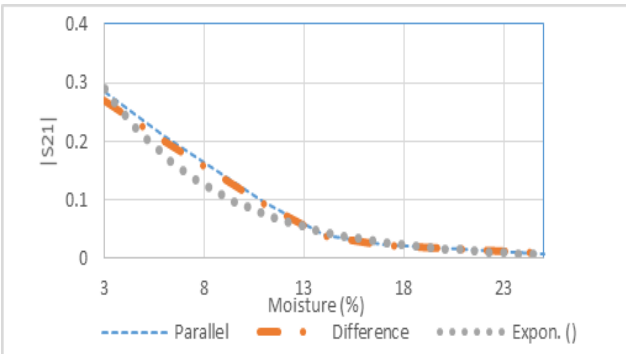


Fig.3 Mutual coupling for 300 MHz versus moisture content.

4. EXPERIMENTAL RESULTS

As we found that mutual coupling decreases as frequency increases. Furthermore, lower frequency has higher coupling than higher frequency. Hence, the frequency of 245 MHz (citizen band) was selected. In this regard, meander line dipole antenna [6] was used instead of straight dipole antenna to miniature the size of the sensor. Fig.4 shows geometry of the sensor which one meander line dipole antenna was used for transmitting 245 MHz and the other two meander line dipole antennas were used for receiving coupled signals. Note that one was for parallel polarization whereas the other one was for perpendicular polarization.

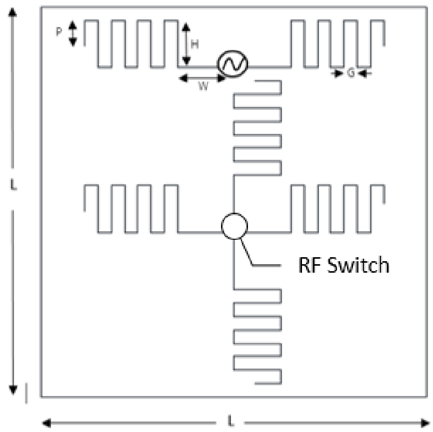
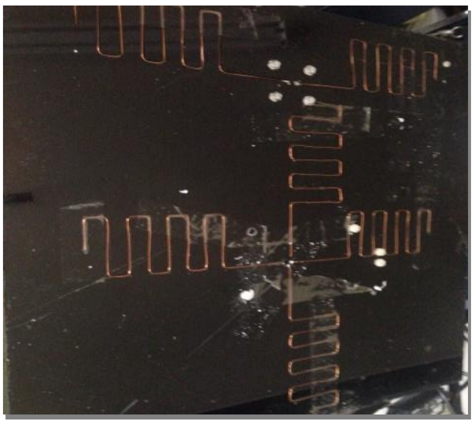


Fig.4 Geometry of the sensor.

L = 280 mm, P = 25 mm, H =40 mm, W = 50 mm, G=10mm.

An oscillator from a 1W transmitter of 245 MHz was used for transmitting signal via a transmitting antenna. The receiving antennas consisting of parallel and perpendicular polarized meander line dipole antennas which an RF switch was used for selecting the polarization state of the receiving antennas.



(a) Photograph of the sensor

(b) Experimental setup

Fig.5 Photograph.

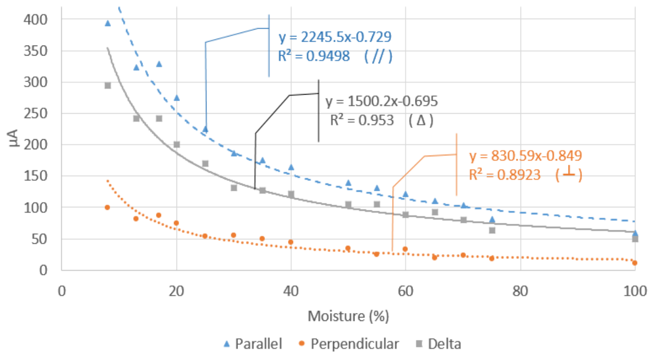


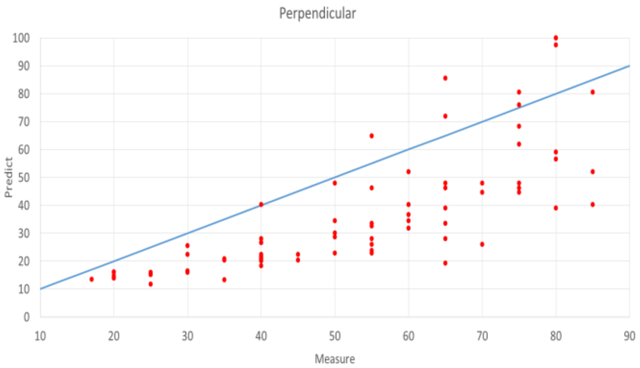
Fig.6 Measurement results.

A Schottky diode was used as a power detector and the output D.C. signal was fed to a micro-ammeter for displaying the mutual coupling. A DM-5 soil tester was fixed in the soil for measuring moisture content where moisture content can be increased by increasing amount of water. Fig.5(a) shows a photograph of the sensor and Fig.5(b) shows the experiment setup.

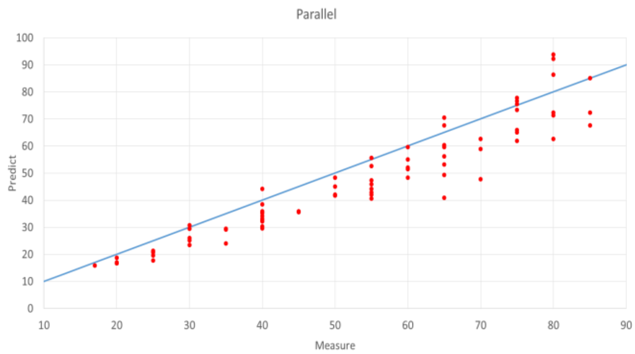
The mutual coupling from only parallel polarization, which has level about four times higher than the perpendicular counterpart may provide good correlation with moisture content but comparing with the difference from the parallel and perpendicular ones, the difference provides better result. Hence, moisture content can be found from the measured difference of both polarizations.

Fig.6 shows the measured difference of mutual coupling current for different moisture content which monotonously decreases with increasing moisture content. Although other polynomials can provide better approximation to the measured results, the power approximation as seen in Fig.6 is sufficiently accurate and the moisture content can be quickly estimated. This is important for real time moisture content measurement in the large area.

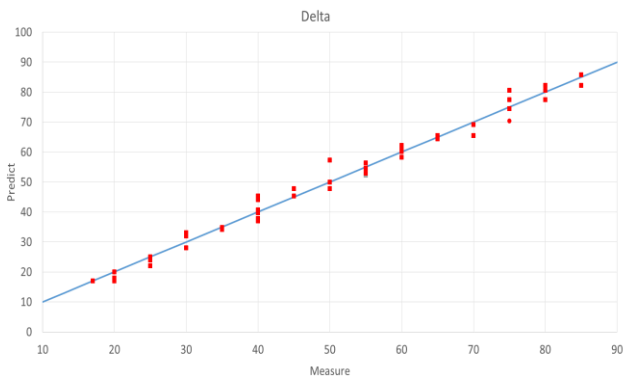
The performance of the sensor showing the predict-measure relation from the experiment is displayed in Fig.7 The errors for perpendicular, parallel and difference are 21%, 6.8% and 1.4%, respectively. The use of difference from two polarizations is much better than the measured results using only one polarization.



(a) Perpendicular



(b) Parallel



(c) Difference of Parallel and Perpendicular

Fig.7 Performance of the sensor.

5. CONCLUSION

According to the requirement of a sensor for measuring moisture content of soil in a large area. A sensor that can provide real time results is proposed. The sensor can measure moisture content by placing it on the surface of soil and the good result is obtained from difference of mutual coupling from parallel and perpendicular polarized meander line dipole antennas. Since the frequency at VHF band of 245 MHz can penetrate deep in the soil and a low cost device can be obtained, the sensor was designed at this frequency. The sensor is miniaturized by designing meander line dipole antennas. The measurement results comparing to the soil tester is essentially good. This sensor can be useful for irrigation system that enhances agricultural products.

References

[1]C.M.K. Gardner, T.J. Dean, and J.D. Cooper, “Soil water content measurement with a high-frequency capacitance sensor,” J. Agric. Eng. Res., Vol. 71, pp.395-403, 1998.

[2]A.E-C Tan, S.Richards, L.Sarrabezolles, I.Platt, and I.Woodhead, “Proximal soil moisture sensing of dairy pasture,” IEEE APS/URSI 2015, Vancouver, 2015.

[3]J.L. Nicole, “The input impedance of horizontal antennas above an imperfect earth,” Radio Science, Vol.15, pp.471-477, 1980.

[4] T.Limpiti and M.Krairiksh, “In Situ moisture content monitoring sensor detecting mutual coupling magnitude between parallel and perpendicuar dipole antennas,” IEEE Trans. Instrumentation and Measurement, vol.61, no.8, pp.2230-2241, Aug. 2012.

[5]J. Cihlar and T. Ulaby, “Dielectric properties of soils as a function of soil moisture content,” CRES Technical Report177-47, November 1974.

[6]H.Nakano, H.Tagami, A.Yoshizawa, and J.Yamauchi, “Shortening of modified dipole antennas,” IEEE Trans. Antennas and Propagation, vol.AP-32, pp.385-386, Apr.1984.