Wideband In-Situ Measurement of Soil Electrical Parameters Using Planar Dipole Antennas

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Abstract— **This paper presents the design of a wideband in-situ probe for measurement of the dielectric properties of soil. A three-dimensional FDTD simulation is used to predict the performance of the probe. The probe uses wideband printed dipole antenna for the transmitting and receiving antennas. The transmitting antenna radiates a differentiated Gaussian pulse that propagates in the soil under investigation. The soil parameters are extracted by mapping the measured complex S_{21} parameter to the values obtained from the FDTD simulation.**

***Keywords*— antenna; conductivity; dipole; electomagnetic; FDTD; in-situ; permittivity; probe; soil; wideband**

I. Introduction

Measuring the soil characteristics in-situ is crucial in applications such as Ground Penetrating Radar (GPR) where interpretation of the radar signal is highly dependent on the ground parameters. Different types of probes were used in the past to measure the dielectric constant of soil [1-4]. Some of these methods only measure the real part of the permittivity [1], other methods are limited in their capability to measure properties at varying depths in the soil [2], some are not suited for in-situ measurements [3] and still others measure soil parameters at frequencies below 1 GHz [4]. Therefore the need exists for a wideband probe that can be used in-situ for soil parameter measurements at varying depths in the ground.

II. Soil Probe design

A. Probe Antennas

The proposed probe design is shown in Figure 1. It uses two Deepace wideband planar dipole antennas (Figure 2). The antennas are immersed in the ground facing each other at a distance of 10 cm. Planar dipole antennas [7] were chosen since they have a low profile for mechanical penetration in the ground, are edge-fed and operate over a wideband of frequencies from 3 to 6 GHz. The radiation pattern of the antennas was measured in the NDU anechoic chamber and was found to be omnidirectional in the horizontal plane (Figure 3). The rods allow for the measurement to be taken at varying depths in the ground. This design is based on the principle of measuring the changes in the amplitude and phase of the wave in the soil's electrical parameters. The probe is portable and well-suited for in-situ measurements in conjunction with portable wideband Vector Network Analyzers (VNAs) currently available in the market. The VNA is connected to a personal computer or processor which maps the measured values of the transmission coefficient to pre-calculated values obtained from 3D numerical simulations of the probe when immersed in different types of soil.

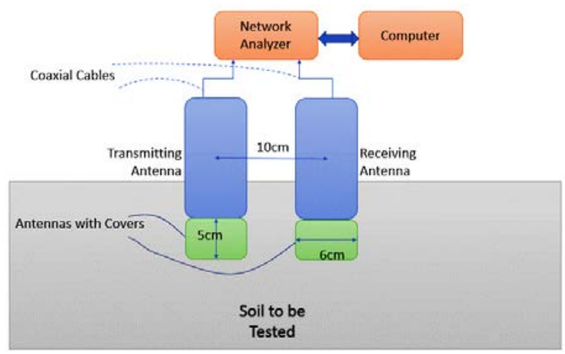

Fig. 1. Probe Design Layout

B. Simuation of Wave Propagation in Soil

Since analytical expressions for the received signal are not easy to obtain due to the multiple interactions of the antennas with the probe structure and the soil, numerical simulations will be used to provide the reference data. This data when compared with measurements can provide the values of the electrical parameters of the soil. The FDTD method [5,6] is used to model the transmitting and receiving antennas in free space and in different types of soil obtained by varying the dielectric constant and conductivity.. The FDTD mesh has a size of 20x20x30cm. A snapshot is shown in Fig 5.

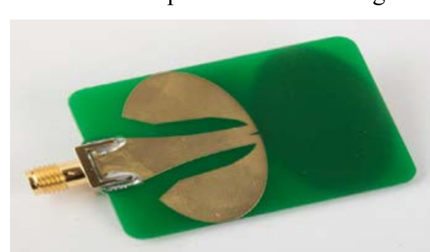

Fig. 2. Wideband planar dipole antenna.

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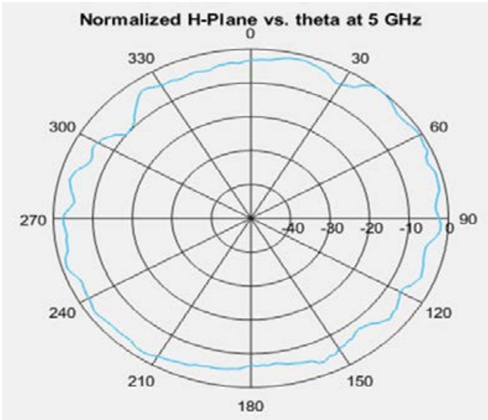

Fig. 3. Measured H-plane pattern of the planar dipole antenna at 5 GHz

III. S_{21} MEASUREMENT

A validation measurement was done using sandstone. A Keysight E5071C VNA was used to measure S_{21} when the antennas were immersed in a 20cmx20cmx30cm length block. Figure 4 shows the measured S_{21} for sandstone and for free space. Comparison of the measured data with the simulated data (Table 1) allows for the extraction of the dielectric constant value of 7.5 and conductivity of 500 mS/m at 5 GHz. Additional validation tests will be carried out using materials with known parameters.

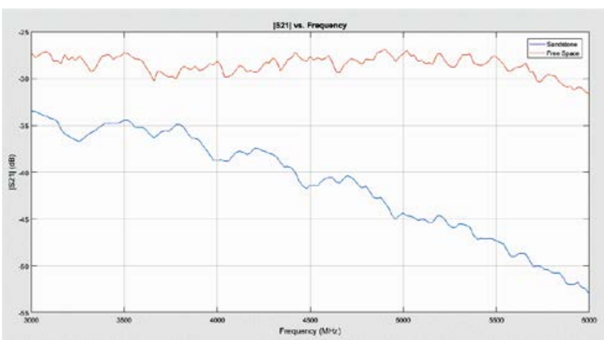

Fig. 4. Measured S_{21} for free space and sandstone.

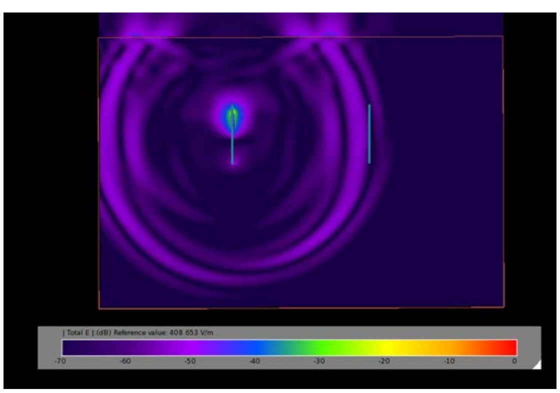

Fig. 5. Snapshot from the FDTD model.

Table 1: Computed S_{21} Magnitude(dB) and Phase(deg) Normalized to free space at 5 GHz versus different values of ε_r and σ.

Frequency=5 GHz					
$\varepsilon_{r,}$ σ(mS/m)	0	40	100	300	500
3	3.5,-220	1.5,-220	-3,-220	-13, -180	-23,-160
5	6, -840	4, -790	0, -530	-13, -450	-22, -350
7	8, -1000	7, -900	4, -950	-6, -800	-14, -550

IV. CONCLUSION

This paper presented the design of a new wideband probe for the in-situ measurements of soil characteristics. The probe can be used with devices such as GPRs and radiometers to help enhance their detecting capabilities. Three-dimensional FDTD simulations were used to predict permittivity and conductivity of materials from measurements of the complex S_{21} values. A validation measurement was done using sandstone. A database of simulations will be constructed to provide higher accuracy by generating S_{21} values at smaller increments of dielectric constant and conductivity and additional validations will be done with other reference materials with known parameters.

V. REFERENCES

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