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A modified dielectric probe for increased measurement volume of soil water content

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Motivation

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- growing shortage of fresh water enforces the necessity of its economical use,
- reasonable use of water resources is required in every sector of the economy (including agriculture),
- the irrigation systems currently used generate significant losses of water,
- it is vital to design sensors able to monitor soil moisture and salinity and automatically store the obtained data.

Measurements of water content

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- direct methods
  - time-consuming
  - destructive
- indirect methods
  - fast
  - non-destructive

Indirect methods

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Depend on monitoring a soil physical or physicochemical properties which are functions of water content e.g. soil dielectric permittivity (ε^*):

$$\varepsilon^* = \varepsilon' - j\varepsilon''$$

TDR
- reliable and accurate
- expensive

FDR
- requires careful installation to avoid air gaps
- inexpensive
- sensitive to temperature, salinity, bulk density

Objective

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- an attempt to develop a sensor which could potentially be used in a mobile platform,
- increase the measurement volume,
- real time measurement,
- reliable sensor performance and accuracy (high frequency measurements, above 200 MHz),
- applicable for automatic use.

Model of the probe

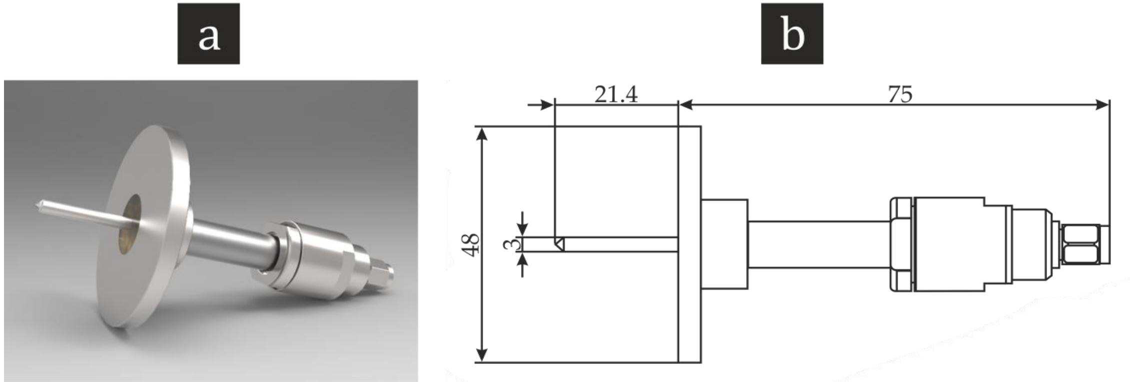

Fig. 1. a) Prototype of the tested probe. b) Respective dimensions of the probe (in mm).

- simulations for different lenght of the central rod;
- simulations for different diameter (*d*) and height (*h*) of the sample using Ansys HFSS software;
- finite element method (FEM);
- frequency range 1 MHz – 6 GHz with the total number of 325 frequency points

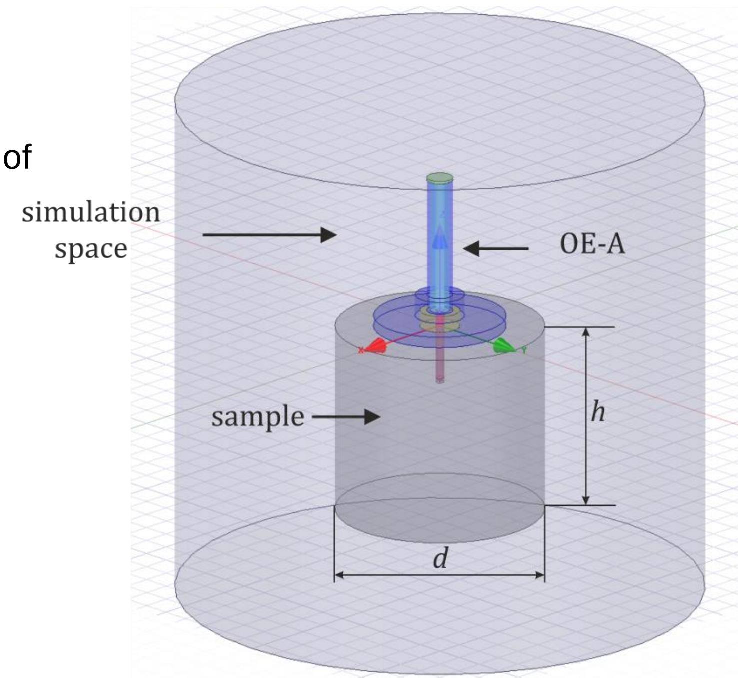

Fig. 2. Prototype of the probe simulated in Ansys HFSS.

Method

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Ansys HFSS S11

Matlab procedure

$$\varepsilon^* = \varepsilon' - j\varepsilon''$$

$$\varepsilon^* = \frac{c_1 S_{11} - c_2}{c_3 - S_{11}}$$

c_1, c_2 and c_3 are complex numbers determined in the open-water-liquid (OWL) calibration using air, distilled water and ethanol as the calibration media

Soils measurements

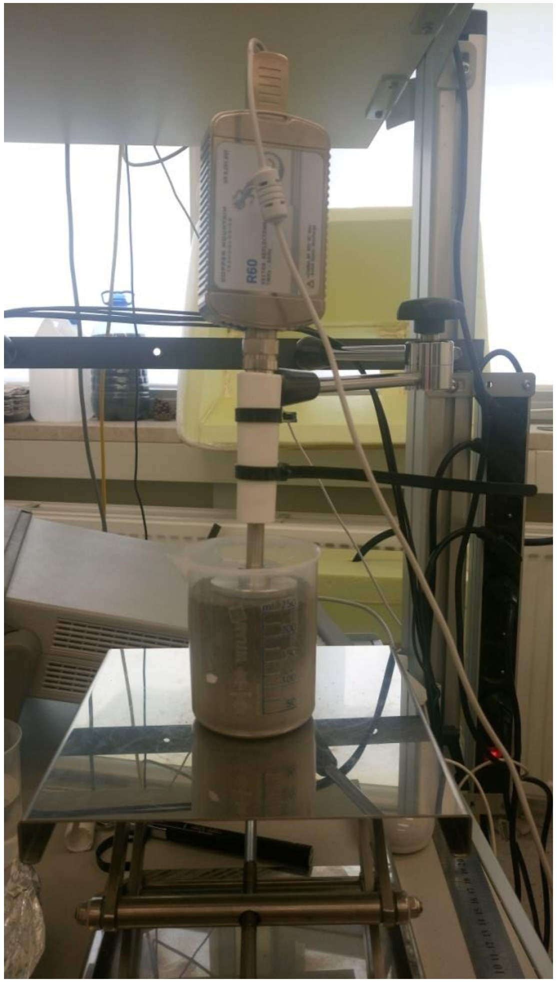

Fig. 3. The VNA measurement system.

Table 1.

Properties of the analyzed soils.

Soil	Texture [%]			Surface area [m^2/g]
	clay	sand	silt	
SKR	3.7	67.5	28.8	3.06
GRT	10.1	13.4	76.5	16.40

Results

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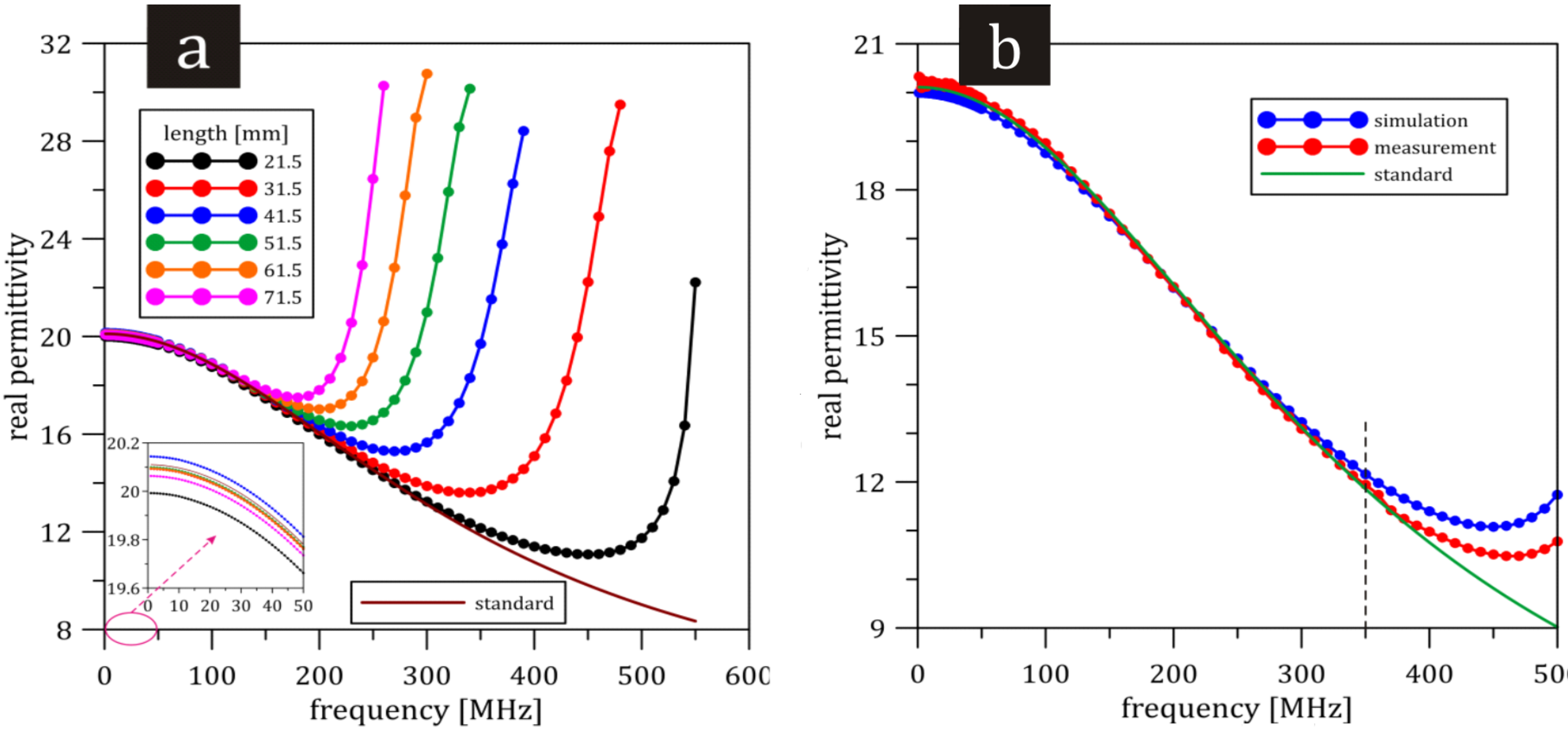

Fig. 4. a) The real part of complex dielectric permittivity simulated for different lengths of the central rod of the OE-A probe. Results obtained for isopropanol. b) Dielectric permittivity spectra of isopropanol obtained from the measurements and simulations. The green line represents the isopropanol spectrum known from the literature while the black dashed indicates the frequency limit of the tested probe.

Results

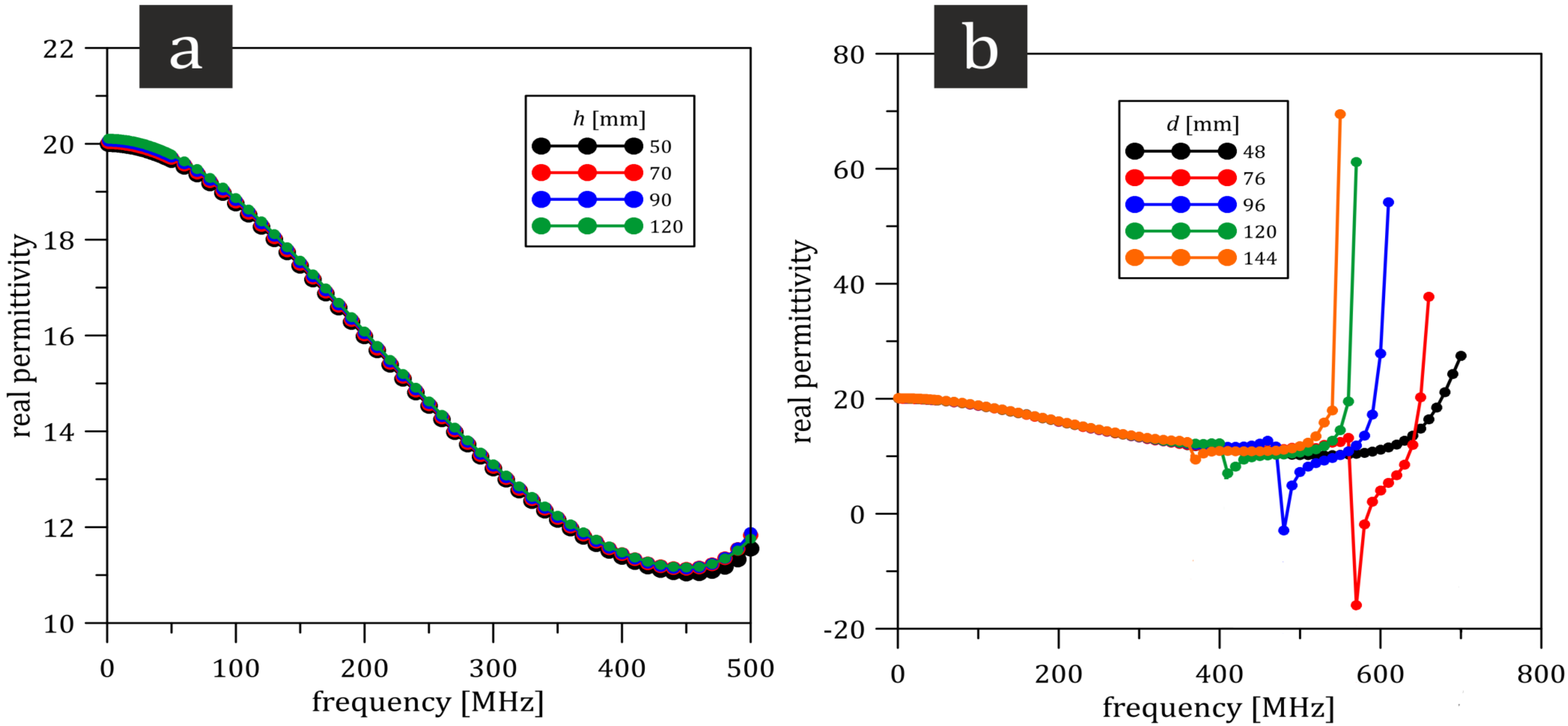

Fig. 5. The effect of changing a) height and b) diameter of the sample on the useful frequency range of the simulated probe.

Results

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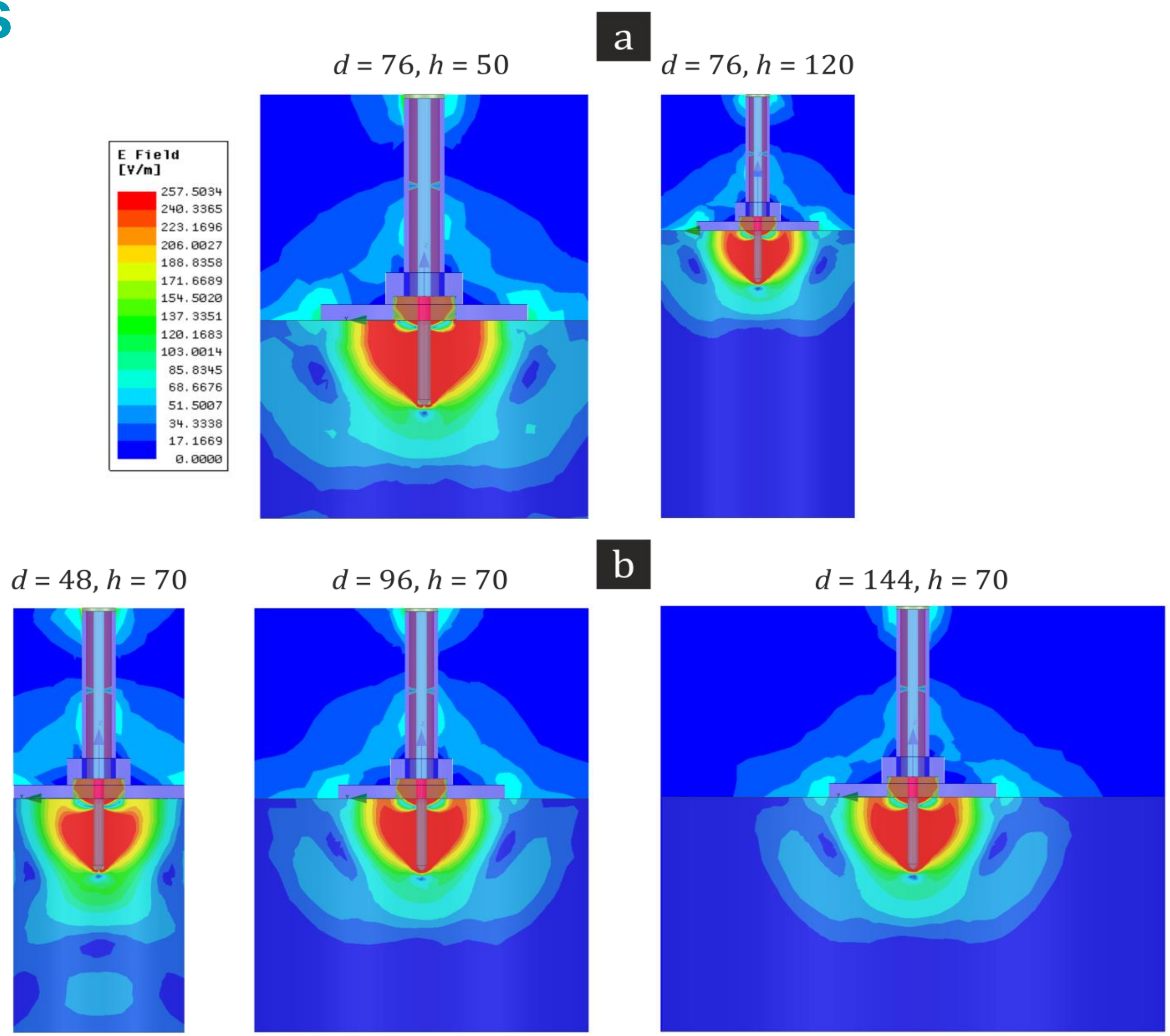

Fig. 6. Field distribution in the sample a) with variable height and b) with variable diameter. Results obtained for frequency 350 MHz.

Results

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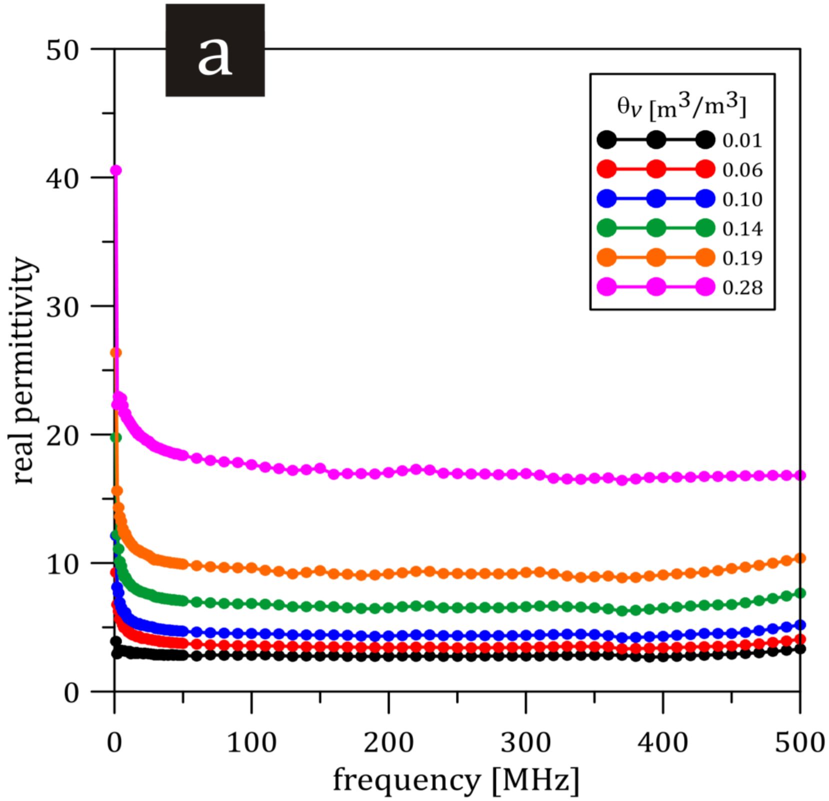

Fig. 7. The real part of complex dielectric permittivity spectra of tested soils: a) SKR and b) GRT with different water content in the frequency range 1 MHz to 500 MHz.

Conclusions

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- the tested probe can be applied for fast moisture measurement with minimal soil disturbance,
- Ansys HFSS simulations enable to predict optimal geometry of analyzed OE-A probe,
- the measurements and simulations results demonstrate that the reliable range of the real part of the ε^* is between 50 MHz and 350 MHz,
- the rod elongation and the increase in the diameter limit the frequency range to the lower values

Read more

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An open-ended probe with an antenna for the measurement of the water content in the soil

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ABSTRACT

Knowledge of water content (WC) in soil is especially necessary in agriculture to assess the individual irrigation state of the plant. Therefore, there is a need to develop sensors able to measure WC in large volumes and in possibly wide frequency range, e.g. by modifications of the classical open-ended (OE) probes which are characterized by low penetration depth of electromagnetic waves. The objective of the research presented in this paper was to test the performance of an open-ended dielectric probe with an antenna (OE-A) in the frequency range 1 MHz–6 GHz for three mineral soils using vector network analyzer (VNA) one port (reflective) measurements. Firstly, numerical simulations of the probe using Ansys HFSS software were performed, followed by the probe calibration on reference materials and measurements of the soil samples to determine soil moisture. The simulation and measurement results of the real part of dielectric permittivity (ε') were in good agreement with literature data up to 350 MHz. ε' obtained for the tested soils was connected with their moisture and the relation between ε' and volumetric water content (θ_v) was determined and compared with the Topp's equation. The obtained results proved that our probe can be used for the measurement of the WC in soils in the frequency range from 50 MHz to 350 MHz.

1. Introduction

Knowledge of water content (WC) in soil is a basic condition in many applications in agriculture, hydrology, forestry and civil engineering. Measurement of WC is required in many fields of research related to the soil (Osman and Barakbah, 2006). In agriculture WC is of great importance for determining effective irrigation management and crop quality maintenance (Walker et al., 2004; Miller et al., 2014; Singh et al., 2018). The irrigation systems currently used generate significant losses of water, so there is a need to develop irrigation systems which minimize water losses and simultaneously satisfy individual plant requirements. One of the possibilities to reduce water consumption is exploitation of mobile system provided with injectors and modules for the identification of plant and soil parameters, due to which the injection will be delivered only to these places where plants require intervention (Janik et al., 2018). Therefore, sensors for determination of soil properties installed on a mobile platform should ensure fast and accurate moisture and salinity measurement, minimal soil disturbance, durability and endurance for multiple insertions in soil, energy efficiency and reliability for long-term maintenance-free field operation (resistance to dust, sunlight and other external conditions). Sensors for mobile measurements developed so far were used to measure water content near the soil surface (Inoue et al., 2001) or their depth of measurement was limited (Thomsen et al., 2007). What is more, data acquisition in Inoue et al. (2001) depended on the speed of a mobile platform. Another limitation encountered in the research was an error caused by interfacial conditions between the probe and the soil surface. In the case of the solution presented in Thomsen et al. (2007), several factors including the soil type, WC, number of repetitions and distance between measuring points influenced daily number of measurements.

Measurements of WC can be classified as direct and indirect. The most common direct method used to measure water content in soil is the thermogravimetric method, often used as a calibration for other techniques. A soil sample is collected from a certain soil depth, weighted, placed in an oven and dried at 105°C. However, this method is time-consuming and involves the destruction of the soil sample, meaning that it cannot be used to repeat measurements at the same location (Gardner et al., 2000).

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