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New TDT probe for soil moisture measurement at various soil-profile depths – numerical study of the sensor sensitivity zone

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Accurate monitoring of soil moisture at various depths of a soil profile is important for hydrological, ecohydrological, soil and climate studies, as well as in agriculture, environmental hazards assessment and environmental remediation monitoring. Soil moisture measurement at several depths of a soil profile can be obtained with the use of multiple devices (e.g. TDR probes) installed at various depths or with the use of a single profile-probe in the form of a tube with sensing elements placed at various distances along the tube. Installation of several probes at various depths has several drawbacks, such as soil disturbance, laborious installation process and a significant risk of damaging the cables that connect the individual probes to an above-ground data logger during measurement-system operation. On the other hand, the output of a profile-probe is sensitive to air gaps between the probe and soil. Also, the mechanical design constraints of a profile-probe negatively impact its measurement accuracy and sensitivity zone, with respect, e.g., to two- or three-rod TDR probes.
The work presents an innovative soil moisture profile-probe based on the time-domain transmissiometry (TDT) technique. The sensing element consists of two metal stripes wound around the probe cylindrical enclosure. No installation tube is required. In the presented design, the sensing element is in a direct contact with the soil.
The aim of the presented research is to determine the impact of the stripes separation and probe cylinder radius on the volume of the sensitivity zone. For the purpose of mitigating the impact of soil heterogeneity and air gaps on the measured moisture values, the probe geometric parameters should be optimized in order to obtain the largest sensitivity zone possible.
The simulations were performed in order to determine the propagation time of the electrical pulse along the transmission line formed by the probe stripes. Its transmission parameters were simulated using FEM technique in Keysight EMpro 3D electromagnetic simulation software in the frequency range 0.01 - 10 GHz for various external radius of the probe cylinder, stripes width, stripes separation distance and surrounding material thickness. Three arbitrary dispersive dielectric media were used as surrounding materials. The pulse response of the probe was obtained using Keysight ADS software.
For the tested geometries and materials, pulse propagation time was obtained as a function of material thickness. The results indicated that the optimal separation distance between the stripes was 15 mm. The optimal external radius of the probe, for which the volume of the sensitivity zone was the largest, was equal to 20 mm. Also, for the selected TDT probe geometry the soil moisture calibration curve was developed on the base of the Topp equation. Further research will involve experimental validation of the obtained results and field testing of the profile-probe prototype.
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