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# TRANSMITÂNCIA DE MICROONDAS, COMO MÉTODO NÃO-INVASIVO PARA A MEDIDA DA UMIDADE DO SOLO, EM RHIZOBOX, UTILIZANDO ANTENAS DE MICROFITA

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**Resumo**: Para a determinação não-invasiva de umidade do solo volumétrico ($\theta_V$ (%)), um sistema de micro-ondas com base na transmissão de ondas eletromagnéticas na faixa de freqüência de cerca de 5 GHz foi desenvolvido, utilizando antenas de microfita. As antenas foram colocados em ambos os lados de um vaso em forma de paralelepípedo fino para investigações raízes, os chamados rhizobox. A avaliação é feita através de parâmetros de dispersão (conhecido como parâmetros S) descrevendo dispersão e propriedades dielétricas de um solo. As curvas de calibração para três meios porosos são apresentados, neste caso foram utilizados dois tipos de solo usados para investigação de raiz, os quais são: o "Nullerde - Einheitserde Typ 0 - Einheitserde- und Humuswerke, e um substrato turfa-areia-pomes – "Dachstaudensubstrat Somi 513"; e microesferas de vidro. Além disso, o perfil de umidade do solo em profundidade de um rhizobox é mostrado e a permeabilidade à água do solo para o substrato de turfa, areia, pedra-pomes é calculado. Os resultados apresentados neste trabalho mostram um potencial de microondas usando técnica de transmitância para a determinação de não-invasiva de $\theta_V$, bem como em estudos de propriedades físicas de um solo e para o controle da distribuição 2D $\theta_V$ em um solo, que irá permitir uma melhor compreensão das raízes crescimento.

**Palavras-chave**: microondas, transmitância, umidade do solo, microfita, caixa rizo

## *MICROWAVE FIELD TRANSMITTANCE TECHNIQUE BASED ON MICROSTRIP PATCH ANTENNAS AS A NON-INVASIVE TOOL FOR DETERMINATION OF SOIL MOISTURE IN RHIZOBOXES*

**Abstract**: For non-invasive determination of volumetric soil moisture, $\theta_V$ (%), a microwave system based on transmittance of electromagnetic waves in the frequency range close to 5 GHz was developed using microstrip patch antennas. The antennas were placed on both sides of a thin parallelepiped-shaped pot for roots investigations, so-called rhizobox. The evaluation is made using scattering parameters (known as S-parameters) describing dispersion and dielectric properties of a soil. Calibration curves for three porous media are presented for two soils, the Nullerde - Einheitserde Typ 0 - Einheitserde- und Humuswerke, and a peat-sand-pumice substrate - Dachstaudensubstrat SoMi 513; and one for glass beads. Additionally, the profile of soil moisture in depth of a rhizobox is shown and the soil water permeability for peat-sand-pumice substrate is calculated. The results presented in this work show a potential of using microwave transmittance technique for non-invasive determination of $\theta_V$ as well as for studies of physical properties of a soil and for monitoring 2D $\theta_V$ distribution in a soil which will allow better understanding of roots growth.

**Keywords**: microwave technique, transmittance, soil moisture, microstrip patch antennas, rhizobox

## 1. Introduction

New tools or approaches are considered to be important for investigation and evaluation of soil-water -plant interactions in the plant phenotyping investigations (FIORANI; SCHURR, 2013). One of the central points that determine root system response to water availability is those that water is usually non-homogeneously distributed in a soil and that heterogeneity significantly increases when drought stress occurs. Thus the development of non-invasive instruments and sensors which allow measuring the soil moisture distribution would open up new approaches to investigate plant strategies dealing either with low water content or, in particular, with heterogeneities in water availability during periods of drought cycles.

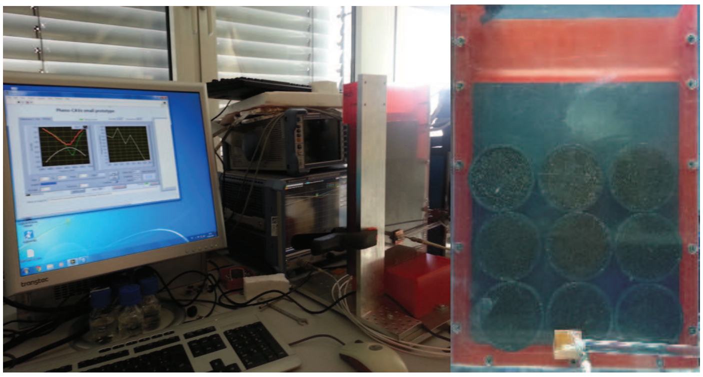
To explore the usage of scattering parameters (S-parameters) at frequency range close to 5 GHz a system with microstrip patch antennas was developed. The antennas were placed on both sides of a rhizobox, which allows measuring non-invasively soil moisture in the box (HERRMANN et al, 2014). Rhizoboxes are normally used to study root growth during plant development and can be applied in the investigations of a root performance. The variation of water content distribution over time was monitored under laboratory conditions.

## 2. Materials and Methods

Each antenna was designed as a λ/2-resonant microstrip patch antenna (CATALDO et al, 2009) on a circuit board with a thickness of 1.5 mm and a dielectric constant, $\varepsilon_{r,sub}$, of 4.4. The antenna was 15 mm in both width and length. A Vector Network Analyzer (ZNB 8, Rohde & Schwarz), is a well-known commercial equipment, and was used to measure changes of scattering parameters (in dBm) at resonant frequency of about 4.8 GHz for each antenna. The network analyzer has a wide dynamic range (up to 140 dB) and ease of operation. The frequency ranges is from 9 kHz to 40 GHz. The transferred, $S_{21}$, and the reflected, $S_{11}$ and $S_{22}$, s-parameters were measured with a resolution of $6x10^{-3}$ dBm. The setup (see Figure 1a) was applied to measure non-invasively soil moisture in rhizoboxes made from Plexiglas and PVC. The boxes had a length of 315 mm, a width of 200 mm, about 5 mm thick walls and were filled with soil. There were two different sizes of rhizoboxes with an internal thickness of either 20 or 40 mm.

To obtain soil moisture profiles positioning system (Feinmess Dresden GmbH) was used to move the antennas with steps at 5 mm, each 4 sec, to displacement and measurement, in vertical direction (length) of the rhizoboxes. The distance between the microstrip antennas was kept constant of 33.5 mm and 61.2 mm for the 20 mm and 40 mm thick rhizoboxes, respectively. We used three different porous media (PM): Nullerde (Einheitserde Typ 0, Einheitserde- und Humuswerke Gebr. Patzer GmbH & Co. KG), peat-sand-pumice substrate (Dachstauden-substrat SoMi 513, Hawita GmbH, Vechta, Germany) (organic matter content of 19.1%) and glass beads (particles size – 0.5 mm) for which calibration curves were obtained by measuring $S_{21}$ and using nine specially designed pots of about 56 mm in diameter that were placed inside a rhizobox (see Figure 1b). The pots were prepared to have the same bulk density of a soil and its different volumetric moisture, $\theta_V$. The bulk densities ($\rho_b$) of the PM used in the experiments were: $\rho_b$ = 0.597 g/cm$^3$ (peat-sand-pumice substrate); $\rho_b$ = 0.298 g/cm$^3$ (Nullerde) and $_b$ = 1.4 g/cm$^3$ (glass beads).

To investigate changes in water distribution, the rhizobox was filled with peat-sand-pumice substrate and 40 ml of deionized water spread uniformly on the top of the dry sample. The rhizobox was then scanned using microstrip antennas every 5 to 30 min over a time period of 2 days. The experiments were made under laboratory conditions at temperature of about 25°C and relative humidity of ~30%. To control the devices and collect the data a LabView based program was used.



(a) (b)

Figure 1. (a) Experimental setup with rhizobox on the left side. (b) Rhizobox with nine pots prepared for calibration data acquisition.

## 3. Results and Discussion

The evaluation of $S_{21}$ dependence on thickness of a rhizobox (20 mm and 40 mm) were made using deionized (DI) water and peat-sand-pumice substrate with $\theta_V$ = 33.4%. Table 1 shows the results obtained during the experiment. It is visible that $S_{21}$ increased approximately in 2 times (meaning decreasing of the transferred power in 2 orders of magnitude, see definition of S-parameters) due to increasing of the rhizobox thickness.

Table 1. Values of $S_{21}$-parameter measured at resonant frequency of antennas for 20mm-rhizobox filled with pure water and for rhizoboxes with different sizes filled with peat-sand-pumice substrate.

| Substrate | Internal thickness of rhizobox | |
|---|---|---|
| | 20 mm | 40 mm |
| | $S_{21}$ (dBm) | |
| Deionized water | - 26.369 | --- |
| Soil with $\rho_{ds}$ = 0.593 ±0.008 g/cm$^3$ and $\theta_V$ = 33.4% | -18.666 | -35.231 |

Calibration data ($S_{21}$(dBm) vs. $\theta_V$ (%)) obtained for three different PM and their linear/polynomial fitting models are shown in Figure 2 and Table 2. The experiments were done for two kinds of soil (Nullerde and peat-sand-pumice substrate) and for glass beads. The 20 mm rhizoboxes were only measured during this experiment.

Nine specially designed pots were used having a PM with different volumetric moisture as it was mentioned above (see Figure 1b). When porous media is relatively dry, before 27% of the $\theta_V$, the behavior of the calibration curves is almost independent of the PM type. A small shift is observed due to both the density of soil and most likely relative permittivity of the media. At higher values of moisture content the soil electrical conductivity plays a crucial role. In this case it is possible to observe a pronounced deviation in the shape of the calibration curve for peat-sand-pumice substrate as it has relatively high electrical conductivity and the behavior can be explained by decreasing of the transferred signal due to increasing of the absorption by this type of soil. Therefore, differences in the PMs physical-chemical properties of could give a reasonable explanation of the obtained results, as they would play an important role in interaction of the electromagnetic waves with the soil-water system at this microwave frequency range.

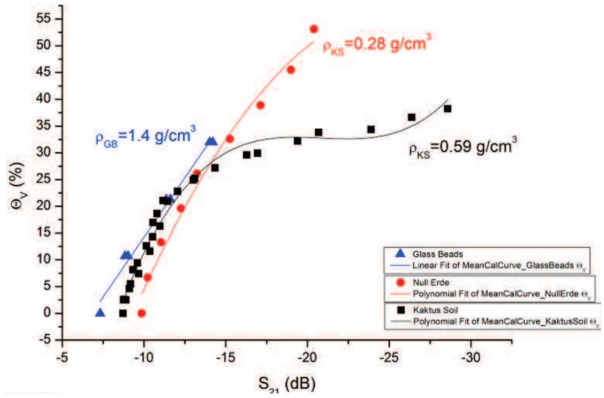



Figure 2. Calibration curves ($S_{21}$ versus $\theta_V$) for two kinds of soil: Nullerde (●) and peat-sand-pumice substrate (■); and for glass beads (▲). Colored values showed on the plot are bulk density of dry soils.

Table 2. Fitting parameters of the linear and polynomial equations for different models that are used to describe the calibration curves obtained for measured samples: glass beads (line), Nullerde (2nd order polynomial) and peat-sand-pumice substrate (3th order polynomial).

| | Constant | $S_{21}$ | $S_{21}^2$ | $S_{21}^3$ | $R^2$ |
|---|---|---|---|---|---|
| Glass beads | -30.3579 | -4.4579 | ------------- | ------------ | 0.9938 |
| Nullerde | -83.0372 | -10.8667 | -0.2111 | ------------ | 0.9798 |
| Peat-sand-pumice substrate | -127.1078 | -23.2650 | -1.1216 | -0.0179 | 0.9799 |

Using the temporal changes of the soil water profiles it is possible to evaluate the soil water permeability. The result of such investigation is shown in the Figure 3. At the beginning of the experiment the volumetric soil moisture, $\theta_V$, at 40 mm below the top of the soil was 31.8% and at 110 mm it was 3.8%. After 2 days $\theta_V$ became similar (3.6%) at both positions. The equations that fit the data over time were 3rd order polynomial and linear for 40 mm and 110 mm distances, respectively. Using these data the soil water permeability was calculated to be about 0.156 cm $h^{-1}$. Referring to Soil Survey Staff, (1999) and Vogel, (2000) the permeability class of this sample can be considered as low.

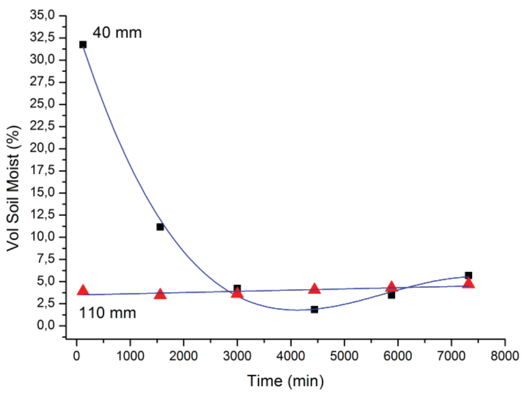



Figure 3. Volumetric soil moisture ($\theta_V$) dependence on time measured at different depths from the top of soil: 40 mm (■) and 110 mm (▲). The information is used to obtain the permeability of Nullerde soil placed in the 20mm-rhizobox.

## 4. Conclusions

The obtained results allows to conclude that the developed non-invasive microwave method using microstrip antennas is an innovative sensing method to measure the water status in rhizoboxes filled with soil. The method can be used to investigate the growth of plant roots together with soil physics properties. Such approach gives an opportunity to apply it for studying and monitoring 2D soil moisture distribution in rhizoboxes.

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