Geophysical Research Abstracts
Vol. 18, EGU2016-6894-1, 2016
EGU General Assembly 2016

Frequency Domain Modelling of Electromagnetic Wave Propagation in Layered Media

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The amount of water in porous media such as soils and rocks is a key parameter when water resources are under investigation. Especially the quantitative spatial distribution and temporal evolution of water contents in soil formations are needed. In high frequency electromagnetic applications soil water content is quantitatively derived from the propagation behavior of electromagnetic waves along waveguides embedded in soil formations. The spatial distribution of the dielectric material properties along the waveguide can be estimated by numerical solving of the inverse problem based on the full wave forward model in time or frequency domain. However, current approaches mostly neglect or approximate the frequency dependence of the electromagnetic material properties of transfer function of the waveguide.

As a first prove of concept a full two port broadband frequency domain forward model for propagation of transverse electromagnetic (TEM) waves in coaxial waveguide has been implemented. It is based on the propagation matrix approach for layered transmission line sections. Depending on the complexity of the material different models for the frequency dependent complex permittivity were applied.

For the validation of the model a broadband frequency domain measurement with network analyzer technique was used. The measurement is based on a 20 cm long 50 Ohm 20/46 coaxial transmission line cell considering inhomogeneous material distributions. This approach allows (i) an increase of the waveguide calibration accuracy in comparison to conventional TDR based technique and (ii) the consideration of the broadband permittivity spectrum of the porous material.

In order to systematic analyze the model, theoretical results were compared with measurements as well as 3D broadband finite element modeling of homogeneous and layered media in the coaxial transmission line cell. Defined standards (Teflon, dry glass beads, de-ionized water) were placed inside the line as the dielectric layers in different configurations. With a Thru Reflect Line calibration (TRL) the influences of connectors and adapters at the coaxial line sample holder were removed.

The combination of the full two port calibration procedure and broadband modeling approach turns out to achieve a good accordance of modeling and experimental results. The next step is the implementation of an inversion to calculate the material parameters of every layer out of the s-parameters of the layered sample.