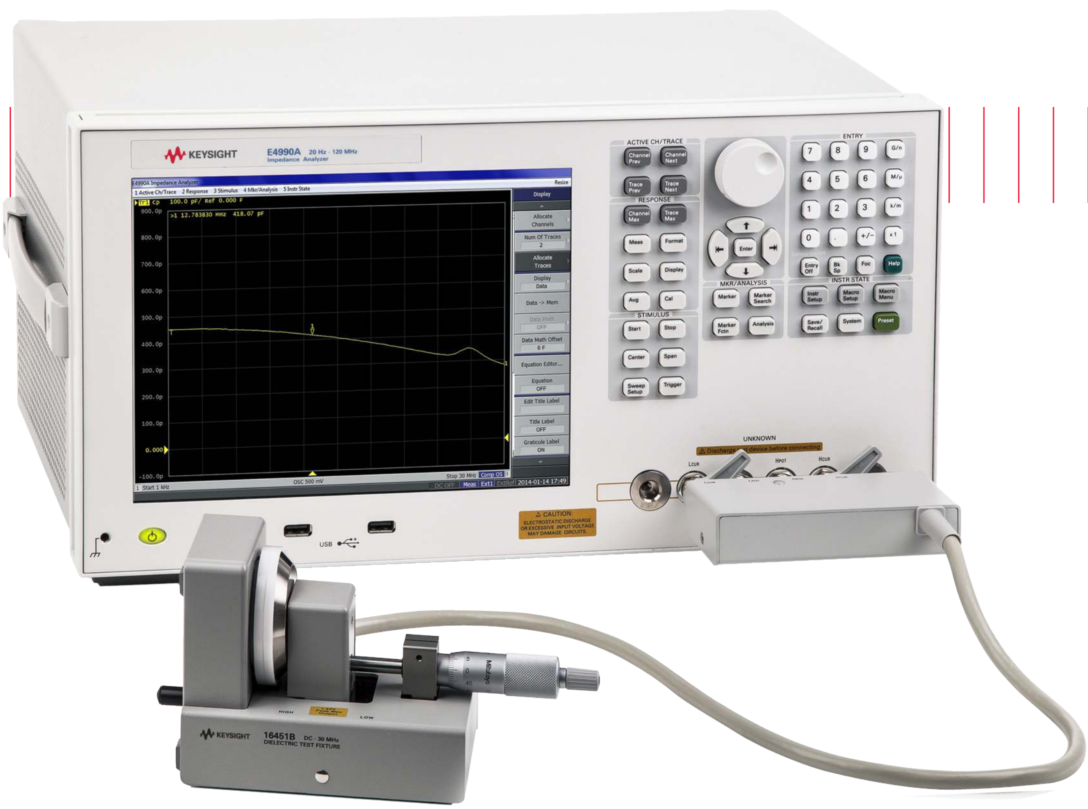
Keysight Technologies
Materials Measurement: Soil Materials

Application Brief



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Overview

Soil materials such as rocks or clay have electrical and mechanical properties as well as with other substances. They often have insulating and small conductive properties that are identified as "dielectric" materials, and they are characterized by their dielectric constant or their permittivity.

The mechanical and electrical properties depend on the composition of the contained material and the binding conditions. By measuring the electrical properties, you can determine the mechanical strength, the measurement of moisture content, and the bonding state of water molecules or particles.

In recent years, attempts to estimate the amount of organic components in the oil shale by measuring its dielectric constant have been made.

The electrical characteristics of soil is also important in the radio wave applications, such as ground penetrating radar, where propagation characteristics of electromagnetic waves are determined by the electrical properties of the medium.

Keysight Technologies, Inc. provides a variety of solutions for evaluating electronic properties of materials from low frequencies to microwave frequencies.

Problem

Attempts to understand the physical properties based on the electrical properties of soil materials have been made. Dielectric properties are due to the polarization of the constituents, but the relationships are not well understood.

There are several mechanisms of polarization: electronic, ionic, molecular (dipole) or interfacial polarization. As frequency increases, the slow mechanisms can no longer follow the changes in the electric field. As a result, the permittivity of each material has a characteristic frequency response.

To characterize the dielectric property of soil materials, it is important to measure the permittivity over a wide frequency range from low frequencies to microwave frequencies, and find distinctive features that correspond to the physical properties.

Solution

For electronic materials, various techniques for measuring the complex permittivity have been proposed and some can be used when measuring soil materials.

At low frequencies, the parallel plate capacitance method is widely used. It forms a capacitor by sandwiching the material in the two electrodes and derives the complex permittivity from the impedance. The Keysight 16451B dielectric material test fixture combined with the Keysight E4990A impedance analyzer is a standard solution at low frequencies up to 30 MHz. Rectangular or disc-shaped samples with polished surfaces can be measured using this solution.

Open-ended coaxial probes are well suited for measurements at higher frequencies. The Keysight dielectric probe kit is one of such a solution and covers from 10 MHz to microwave frequencies, when used with a network analyzer or the Keysight E4991B impedance analyzer. Measurements can be made by pressing the probe on the surface of the sample.

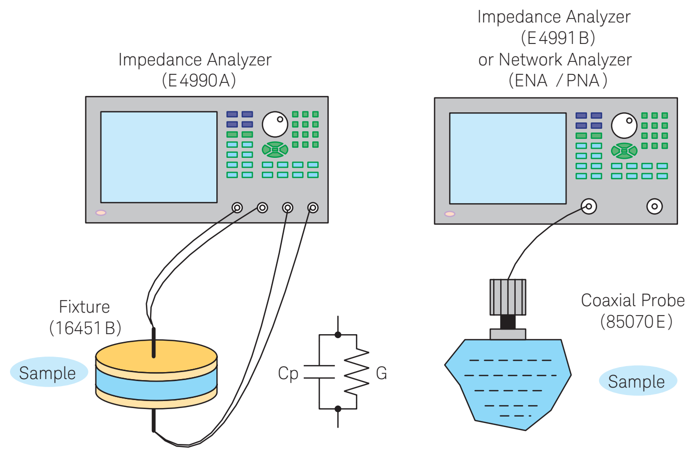

Figure 1. Typical system configuration

Rocks and clay contains moisture in the grain boundaries, where the conductive ions are dissolved. When an electric field is applied, the ions move through the water, which gives conductivity to the soil material. The water molecules exhibit polarization by changing their orientation. The relative permittivity due to this polarization is large compared to that of vacuum, around 80 below 100 MHz.

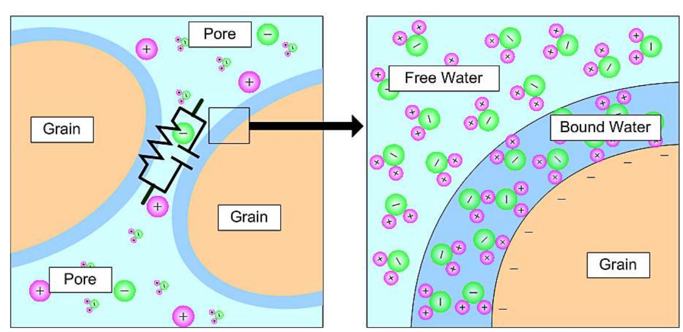

Figure 2. Electrical image of soil material

The conductivity and the permittivity are determined by the type of ion or molecule, volume fraction, and their ease of movement. This allows you to determine the moisture content or other composition of the material by the permittivity measurement, which leads to the analysis of physical properties.

As frequency increases, the molecular dipole cannot follow the change in electric field. As a result, the real part of relative complex permittivity (ε') rolls off and the imaginary part or the loss factor (ε") shows a peak at each critical frequency. For water molecules, the critical frequency is around 22 GHz. If the surface of the grain is electrically charged, the water molecules are tightly bound to the grain surface and difficult to dissociate. Since the critical frequency of bound water is lower than that of the free water, they can be separately estimated by measuring the broad-band frequency characteristics.

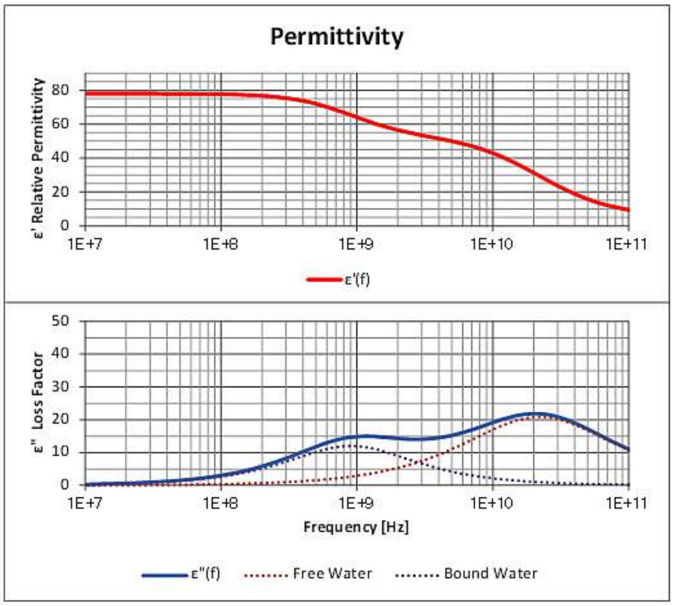

Figure 3. Complex permittivity of free & bound water (Conceptual diagram)

It is recommended to apply these features of the dielectric measurement to the analysis of oil shale since the complex permittivity is the mixture of the composition of the contained material and its frequency characteristic is sensitive to the binding condition, it has sensitivity to the moisture content, organic compound and, salinity. The possible goal is in-situ determination of the oil contents in the shale and it should be done by permittivity measurements along with other analytical methods for oil shale with various compositions.

Macroscopic aspect of the dielectric properties of the soil is essential for the analysis of the propagation characteristics of the ground penetrating radar (GPR). In a soil media, propagation velocity and attenuation of an electromagnetic wave is determined by the relative permittivity (ε') and the conductivity ($\sigma = \omega\varepsilon_0\varepsilon''$) respectively. The frequency is selected considering the spatial resolution and the penetration depth, usually in the range of 10 MHz to 10 GHz.

Conclusion

Soil materials have electronic properties depending on their structure, contained materials and the compositions. They can be characterized by the relative permittivity and the conductivity, or complex permittivity.

The complex permittivity is derived from the impedance, which can be measured by a parallel plate capacitance for low frequencies and a coaxial probe for high frequencies.

Moisture contents in the soil material give a large permittivity and salinity or other ions are the source of the conductivity. It is considered to apply these characteristics for the determination of the composition of rocks and clay as well as oil shale.

Molecular polarization shows roll off around 22 GHz for free water, however the frequency decreases for bound water. Separate analysis between free and bound water is possible when measurements are made using a wide frequency range.

Keysight Technologies, Inc. provides measurement solutions for both configurations; parallel plate capacitance method and open-ended coaxial probes along with impedance/network analyzers and measurement software for calibration and analysis. For more information, application notes and white papers are listed under references.

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