Measuring IP effects at high frequencies: first lab and field data from 0.001 Hz - 250 kHz

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The electrical resistivity of nearly all natural materials is more or less frequency dependent. This is caused by electrochemical interactions between the ions of the pore space fluids and the inner pore surfaces. These interactions express themselves as an additional conductivity mechanism, next to that of the fluids. In the frequency range one can observe with increasing frequency, a steady decrease of the resistivity. Accompanied by this is a phase shift between the injected current and the resulting voltage. In the first approximation, the phases are proportional to the increase of the resistance. Therefore the phase spectrum contains all information which can be obtained from electrical measurements, except the DC resistivity. Numerous investigations were done in the lab-scale on sandstone samples. Scott and Barker (2003) found a convincing correlation of dominant pore throat D_0 and the frequency at which the peak phase angle occurs for a range of sandstones obtained from sites across the UK. In doing so, large pore radii correlate with phases at low frequencies and small pore radii with phases at high frequencies. The determination of pore radii distribution is one of the most important parameters of Petrophysics. In order to determine the widest possible pore radii distribution with the method of Induced Polarization, the resistivity must, therefore, be measured over the widest possible frequency range.

Instrument and cable set-up

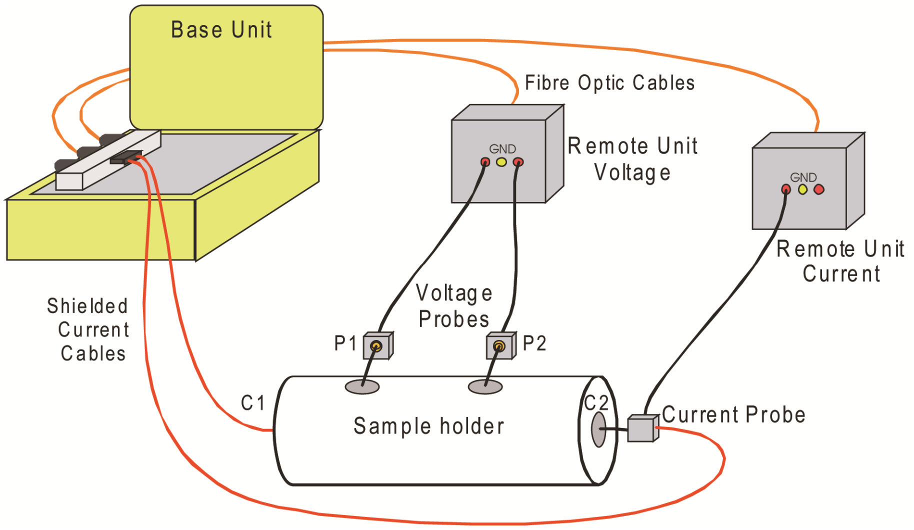

Fig. 1: Schematic diagram of the new instrument Chameleon. The base unit contains a signal source and transmitter. A minimum of two remote units digitize the analogue signals of the current and the voltage probes. The cylinder represents a container with sample material.

The expansion to high frequencies (up to 250 kHz) however, puts high demands on the measuring technique. For the measuring technique, the measuring instrument itself is important and also the indispensable measuring lines. To fulfil these requirements, we have developed a new type of measuring system called Chameleon (Fig. 1). We must demand a very high synchronicity of the measuring channels from the measuring instrument. In addition, unwanted couplings between them must be avoided. We achieve this through a physical separation of the system components. Optical fibres are used for data transfer and synchronisation; failing this, the required phase resolution would not be reached. Unwanted couplings can also appear between the measuring lines. These can be effectively stopped if the measuring lines are chosen to be as short as possible. Our measuring system permits the measuring electronics of every measuring channel to be placed directly at every electrode (here C2, P1, P2). An additional very important aspect for measurements at high frequencies is the input capacitance of the measuring electronics. With our apparatus it is just 1.5 pF. However, even this value is too high, as soon as the object has a low porosity or is unsaturated. As a rule both cause heighten the resistivity. This, together with the input capacitance, has an effect like a low-pass filter on the resistivity measurement. Luckily, this effect can be almost exactly quantified and numerically compensated.

Case Study 1 - Sandstone Sample

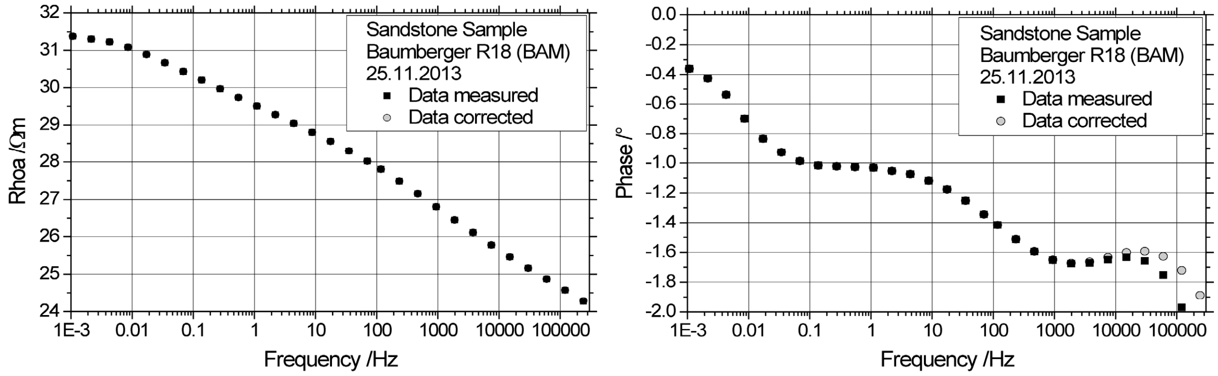

Fig. 2: Measured resistivity spectrum of a sandstone sample.
Sandstone sample and sample holder were provided by Dr. S. Kruschwitz (BAM, Berlin).

Figure 2 shows a resistivity spectrum (amplitude and phase), which was measured from a fully saturated sandstone sample in our laboratory. The sandstone sample (Baumberger R18) as well as the sample holder were kindly supplied to us by Dr. S. Kruschwitz (Federal Institute for Material Research and Testing -BAM). Also shown next to the measured data (the black dots), are the corrected data, which are freed by effects from the input capacitance of the instrument (the red dots). The spectrum shows two phase maxima, one of which is at 0.2 Hz and another at 2 kHz. With regard to the directions given in the instructions, one can assume that this sample exhibits two dominant pore radii. The demonstrated maxima at 2 kHz, furthermore, shows that also at high frequencies relevant information exists about the pore space, and that we could clearly detect this with our new instrument Chameleon.

Case study 2 - Small-scale field measurement

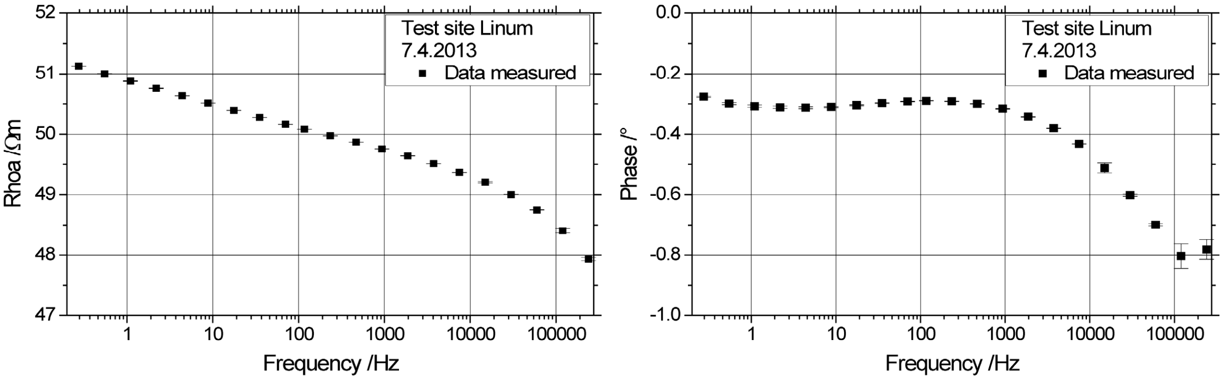

Fig. 3: SIP data measured at test site Linum (30 km north of Berlin). Squared array. Electrodes spacing: 1 m.

Figure 3 shows the result of spectral resistivity measurements at our test site Linum. The amplitude and phase were measured between 0.3 Hz and 250 kHz. For these measurements a squared array was used with an electrode space of 1 m. Despite the good conductivity of the ground, electromagnetic effects (inductive coupling, skin effect) can still be neglected by this small scale measurement set-up. The somewhat heighten error bar for both of the highest measured frequencies probably arises from disturbances from long wave range radio transmitters. The case study proves that the specific resistance with small-scale configurations can also be precisely measured at high frequencies. We see the application in the characterization of up to ~50 cm deep grounds. For example, information about the roots of trees and agricultural crops for food or bioenergy production can be obtained. We also see potential for application in archeology.

Reference

Scott, J.B.T. and Barker, R., 2003. Determining pore-throat size in Permo-Triassic sandstones from low-frequency electrical spectroscopy. *Geophys. Res. Lett.*, 30(9), 1450.