

The paradox of the measuring electrodes in IP

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In the IP measuring chain, measuring electrodes sample the potential toward the very high impedance voltmeter. Modelled by a set of passive electronic components, the measuring electrodes should be invisible, thanks to the quasi infinite input impedance of the instrument input, as shown on Fig. 1. But they are not, from experimental evidence. Figure 2 shows the result obtained in a tank experiment by using three kinds of electrodes and two electrolytes: 1) copper and CuSO₄ solution, 2) non-polarisable electrode SDEC (Pb/PbCl₂) and NaCl, 3) stainless steel with tap water. Al though it is why one prefers non polarisable electrodes in practice, there is a paradox.

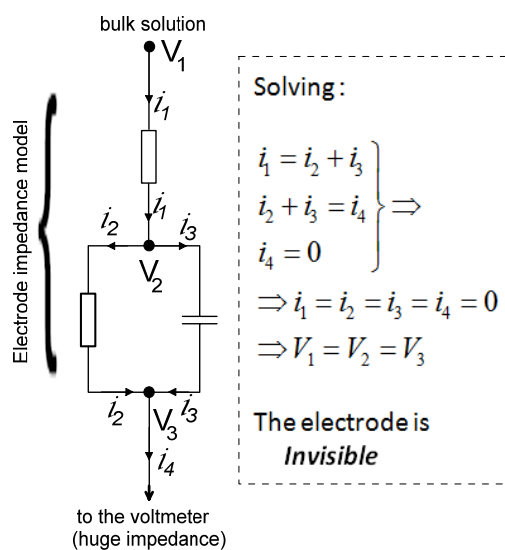


Fig. 1: IP measuring chain. Thanks to the huge impedance of the instrument input, any complex (passive) electrode should be neutral and not visible in a four-electrode array data set.

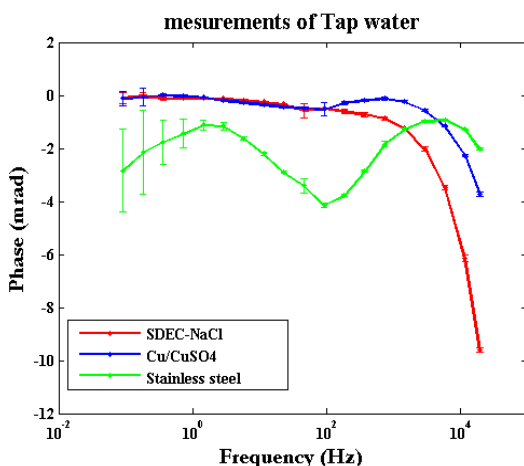


Fig. 2: Results of a classical measurement of tap water, showing the electrode impact on the data.

Clearly, the nature of the electrode impacts the data. It is particularly noticeable when using stainless steel electrode, where these effects at low frequencies are caused by the diffusion phenomena and can be modelled by a Warburg element. But the fact that at high frequencies the same behaviour and curve shape arises, when using non-polarisable or polarisable electrodes, suggests that the phenomenon could be general.

When considering the electrical double layer, a minimum voltage is required to get some “faradic current” crossing this redox potential barrier (it is the electrolysis threshold). But how does the same barrier behave when we try to “transport” passively the (small) potential from the bulk

electrolyte to the FET grid in the input stage of the instrumentation amplifier? The fact that the barrier is not overridden by the ordinarily small potential to be measured makes the current extremely low and even negligible. Actually, electrostatic influence is possibly the main phenomenon determining the potential in the metal of the electrode and finally on the FET grid.

Possibly, this kind of response should be taken into account in the whole protocol by introducing an equivalent electronic component between the potential electrodes P_1 and P_2 , at least to better analytically split the medium own response from the whole.

The objective of our work is to interpret all these effects and then model them as an equivalent electronic circuit. Impedance measurements of tap water or conductive solutions underline the strong effect of various types of electrodes. While “non-polarizable electrodes” give usually simpler results than metallic electrodes, the obtained frequency impedance is generally not reduced to the conductivity/permittivity response of the solution.

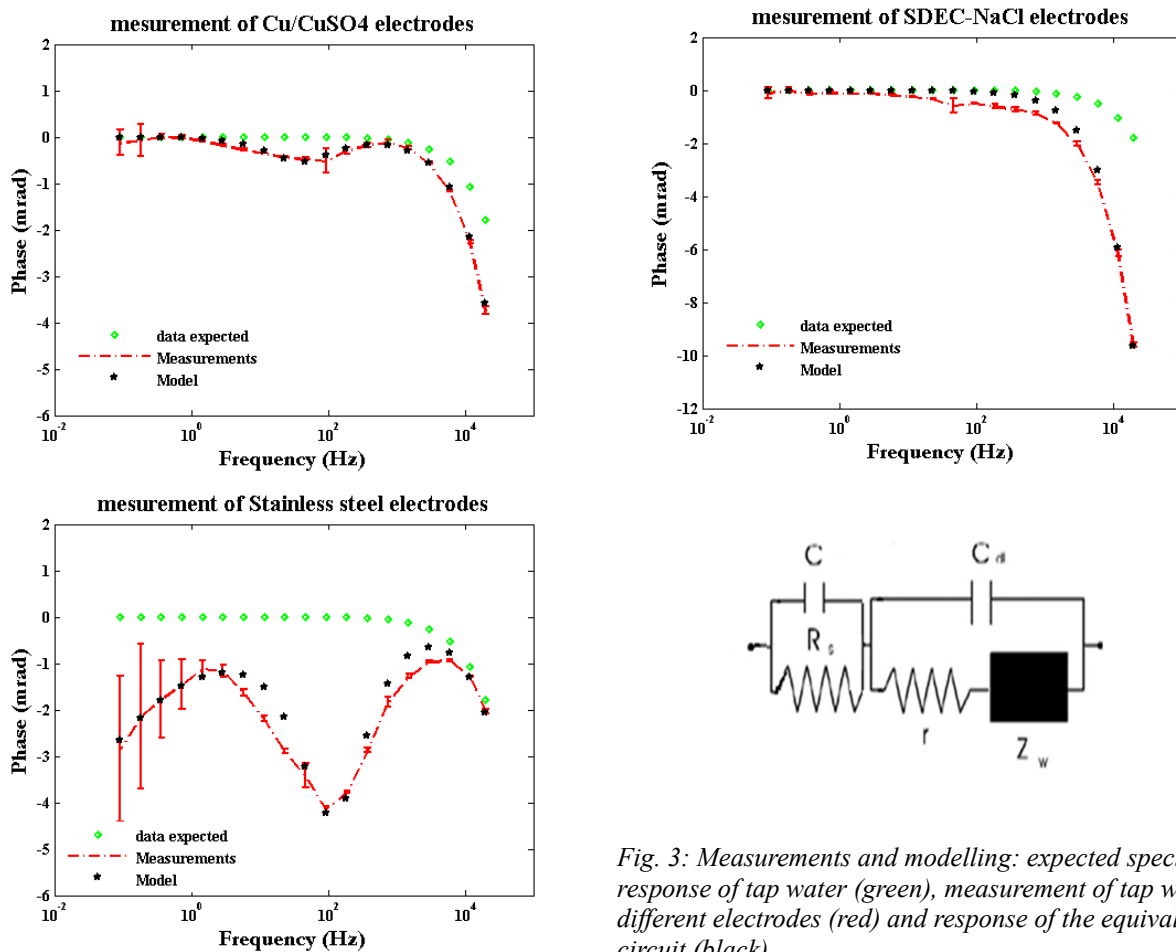


Fig. 3: Measurements and modelling: expected spectral response of tap water (green), measurement of tap water by different electrodes (red) and response of the equivalent circuit (black).

Figure 3 shows the equivalent circuit proposed to model the phenomena at high frequencies, and the modelling results for the three types of electrodes. Low frequency phenomena occur mainly with metal electrodes, and they are generally modeled by a “Warburg” type component (Boadu and Seabrook 2006, Ragheb and Geddes 1991). To adjust the high frequency discrepancy with respect to expected response, we have to add a capacitance element (C) connected in parallel with the resistivity of solution (R_s).

This work underlines the need of taking into account the influence of the electrodes on the spectral induced polarization measurements, over the the entire frequency band.

References

- Boadu, K.F. and Seabrook, C.B., 2006. Effects of clay content and salinity on the spectral electrical response of soils. *J. Env. Eng. Geophys.*, 11, 161-170.
- Ragheb, T., and Geddes, L.A., 1991. The polarization impedance of common electrode metals operated at low current density. *Ann. Biomed. Eng.*, 19, 151-163.