

# Experiment 4: Spectral induced polarization (SIP)

## 1 Task

In this experiment, the frequency-dependent, complex, electrical conductivity is to be measured and the influence of polarizable particles of different sizes is to be investigated. These measurements are to be compared with a measurement on pure quartz sand.

## 2 Fundamentals

The electrical conductivity is one of the most important physical properties of rocks. It can tell about the pore space and the fluids contained in it, about the mineral composition and about the processes occurring at the interfaces. Specifically, it is traditionally used for mineral prospection of ore deposits. The electrical conductivity  $\sigma$  is generally a complex-valued (denoted by \*), frequency-dependent quantity that can be described by means of a real and an imaginary part (denoted by ' and "", respectively) or by means of magnitude and phase shift  $\varphi$  (in ° or mrad):

$$\sigma^*(\omega) = \sigma'(\omega) + i\sigma''(\omega) = |\sigma^*| \cdot e^{i\varphi} \quad (1)$$

Here  $\omega$  denotes the angular frequency ( $\omega = 2\pi f$  with frequency  $f$  in Hz). Its inverse is the resistivity  $\rho^*$ :

$$\rho^*(\omega) = \frac{1}{\sigma^*(\omega)} = \rho'(\omega) + i\rho''(\omega) = |\rho^*| \cdot e^{-i\varphi} \quad (2)$$

If the interface conductivity in the rock is due to a specific cause (e.g., polarizable particles of uniform size), the complex, electrical resistivity can often be described using the Cole-Cole relaxation model:

$$\rho^*(\omega) = \frac{1}{\sigma^*(\omega)} = \rho_0 \left( 1 - m \cdot \left( 1 - \frac{1}{1 + (i\omega\tau)^c} \right) \right) \quad (3)$$

Here  $\rho_0$  is the electrical resistance at direct current,  $m$  the chargeability,  $\tau$  the relaxation time and  $c$  an exponent. Variations in the frequency of the relaxation ( $\tau$ ), its strength ( $m$ ) as well as its shape ( $c$ ) allow conclusions to be drawn about the cause of the relaxation.

## 3 Experimental Set-up

The following components and utensils are required for carrying out the experiment:

- Measuring device "SIP Fuchs III" with two "Remote Units" for current and voltage measurement
- Cables (Banana, BNC)
- EKG electrodes with connecting cables

The following figures 1 to 4 show the setup for SIP measurement and the controls of the measurement software.

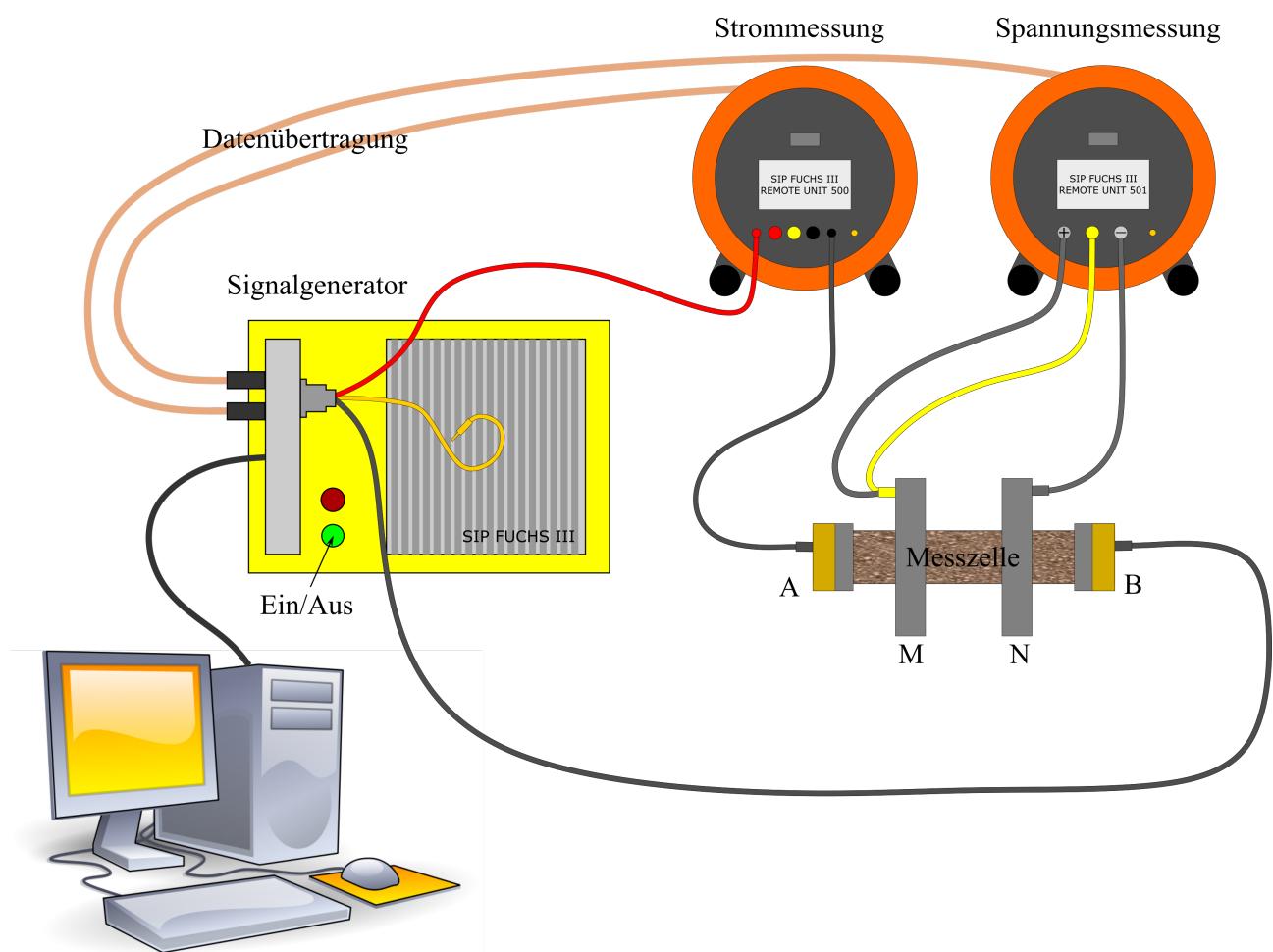


Figure 1: Schematic view of the measuring setup with a SIP measuring cell for unconsolidated rocks and the "SIP FUCHS III" measuring device.

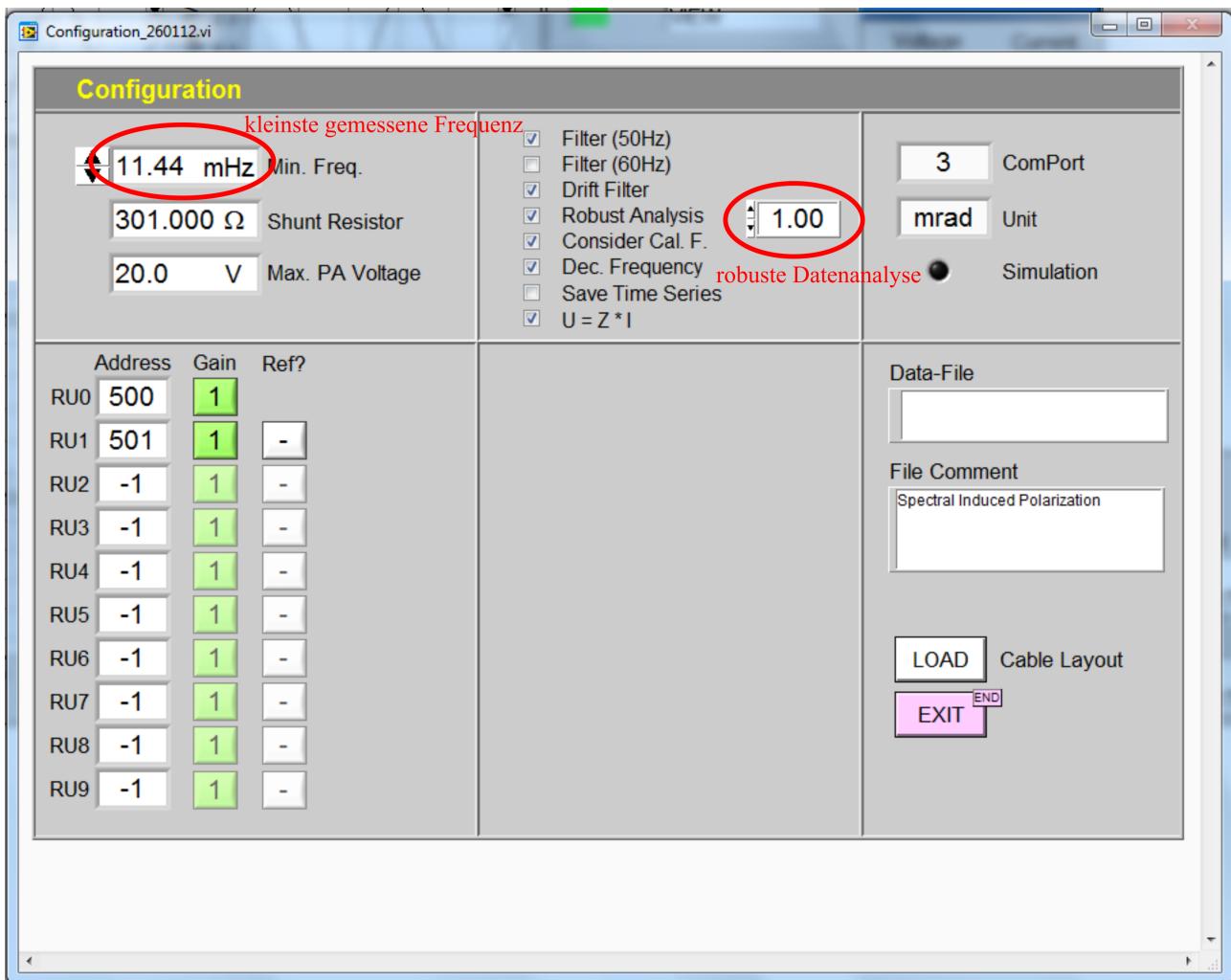


Fig. 2: Configuration window of the SIP-Fuchs III measurement software.

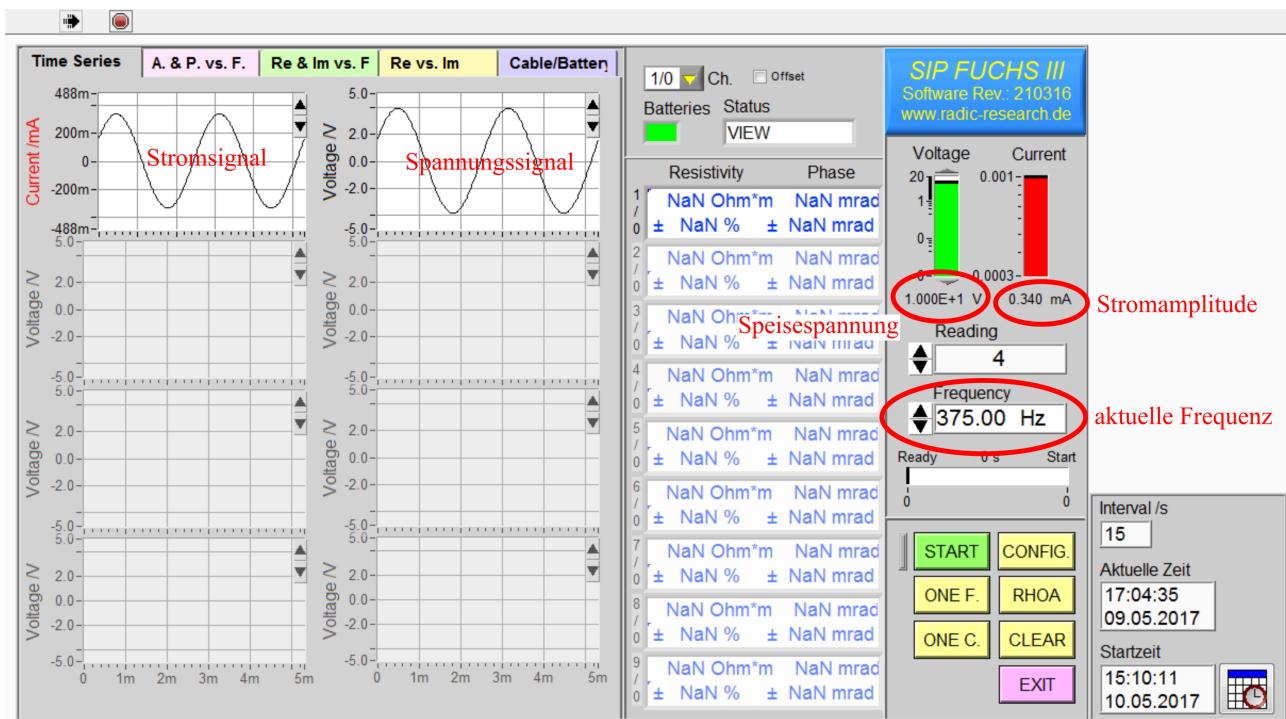


Fig. 3: "Time Series" tab of the SIP-Fuchs III measurement software.

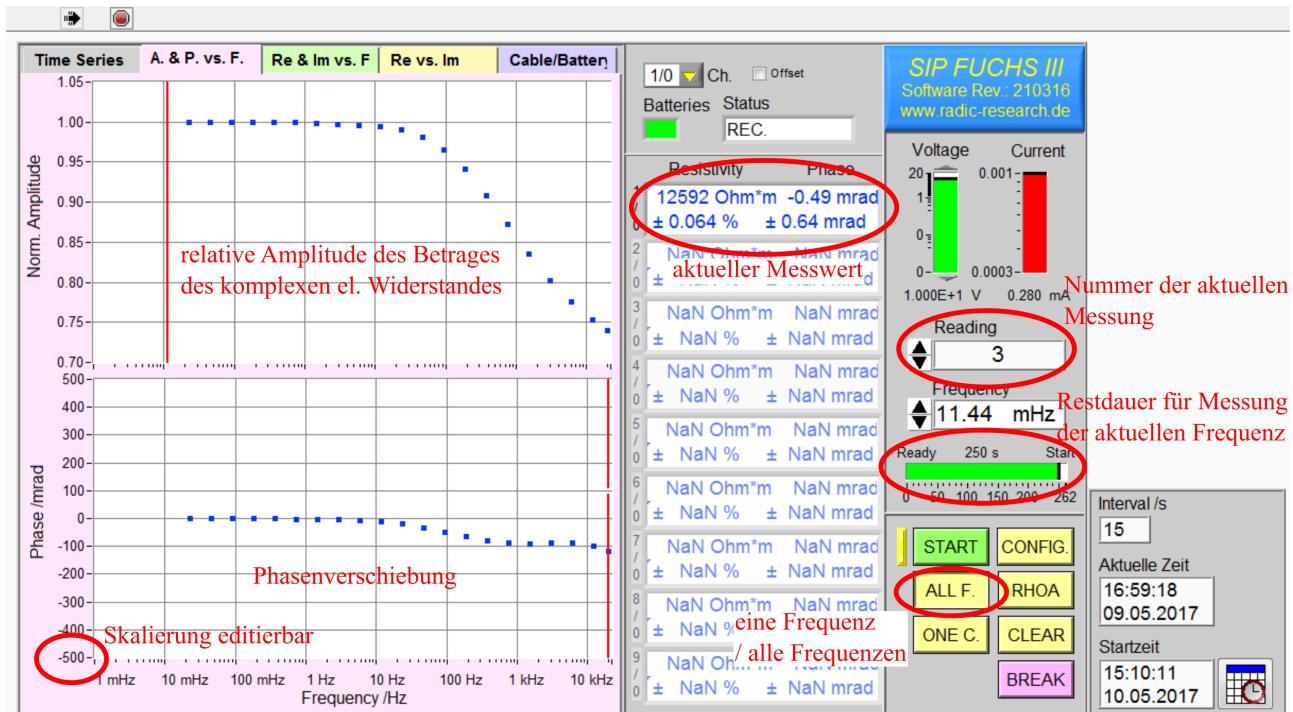


Fig. 4: Tab "A. & P. vs. F." of the SIP-Fuchs III measurement software.

## 4 Implementation

1. Switch on the measuring device (green button). It should warm up a little before starting the measurement.
2. Open the measuring software (shortcut "SIP measuring program" on the desktop). Start the program using the arrow at the top left of the program window. The "Configuration" window (Fig. 2) appears.
3. Set approx. 11.44 mHz as the lowest frequency. Select the value 1.00 for the robust analysis. Check that all check marks are set as in Fig. 2. Close the menu with the "EXIT" button. The view as in Fig. 3 appears.
4. Assemble the SIP measuring cell. Attention: Please tighten screws only hand-tight.
5. Prepare a completely water-saturated specimen with the first quartz sand-galena mixture:
  - a) Store the measuring cell vertically and fill it about halfway with tempered tap water. Make sure to remove as much air as possible from the slots of the potential electrodes. Document the fluid conductivity.
  - b) Fill the sample material into the cell while stirring and tapping until it is completely filled. Take special care to distribute the galena particles as evenly as possible.
  - c) Clean the top surface of the cell and seal it. Check your installation for air bubbles. If necessary, open the cell again and remove the air bubbles.
6. Connect the measuring cell as shown in Fig. 1.
7. Look at the current and voltage signal at different frequencies. Adjust the supply voltage (green indicator bar can be moved with the mouse) so that approximately a current of 0.4 mA flows at 20 kHz.
8. Set the "ONE F. / ALL F." button so that it displays "ALL F.".
9. Switch to the tab "A. & P. vs. F." tab of the measuring software.

10. Set the correct number of the next measurement (Reading 1 = measurement of the first sample, etc.). **caution:** If the setting of the next reading is missed, already measured data will be overwritten!
11. Set the current frequency to 20 kHz and start the measurement with "START". The measured values appear one after the other in the form of the relative resistivity magnitude and the phase shift of the complex resistivity. The latter is always negative (see equation 2).
12. After finishing the measurement: Create a backup copy of the measurement data (shortcut "Measurement folder" on the desktop, file "results.res").
13. Disconnect the cable connections on the measuring cell. Empty, disassemble and clean the measuring cell. The sample material is to be reused.
14. Repeat steps 4 to 13 for the second silica sand-galena mixture as well as the pure silica sand.
15. Clean all the utensils used and the measuring station.

## 5 Processing

- Extract the frequencies, electrical resistances, phase shifts and errors from the ASCII files. Convert the el. resistances into resistivities (geometry factor  $K = 0.0092 \text{ m}$ ). Plot the spectra double logarithmically as resistivity magnitude and negative phase, and as real and imaginary parts of the conductivity. Include error bars based on the measured uncertainties. Pay attention to the units in your calculations as well as the rules of error propagation.
- Check the applicability of the Cole-Cole model to the measured data. If applicable, determine the Cole-Cole parameters  $\rho_0$ ,  $m$ ,  $\tau$  and  $c$ . Check also the Debye decomposition approach.
- Interpret your results and discuss error influences. In particular, discuss the relationship between the frequency characteristics and the Cole-Cole parameters as well as the properties of the galenite particles and the sand.

See notebook:

[https://github.com/TUBAF-EM/MineShaft\\_Geophysics/blob/main/SIP/example/example.ipynb](https://github.com/TUBAF-EM/MineShaft_Geophysics/blob/main/SIP/example/example.ipynb)

```
from pygimli.physics import SIPSpectrum
# read in data
spec = SIPSpectrum("Py6p_grobA.txt", k=0.0297)
print(spec)
# check Kramers-Kronig consistency
fig, ax = spec.showDataKK()
fig.savefig("pyritGrob-rawKK.svg")
# try to get rid of high-frequency coupling
spec.removeEpsilonEffect()
spec.showAll()
# repeat Kramers-Kronig
fig, ax = spec.showDataKK()
# limit frequency range if necessary
spec.cutF(1000.0)
spec.cutF(0.1, down=True)
fig, ax = spec.showData()
# check Cole-Cole fit
spec.fitColeCole();
fig, ax = spec.showAll()
# run Debye decomposition
```

```
spec.fitDebyeModel()  
fig, ax = spec.showAll()
```

## 6 Report

In the report, describe the measurements performed and their evaluation. Use meaningful diagrams, explain their calculations and document the raw data in tables. Also answer and discuss the following questions:

- The complex conductivity / complex resistivity can be written in terms of magnitude and phase shift or in terms of real and imaginary part (equations 1 and 2). Both formulations describe the quantities completely, but the individual components have different meanings and are subject to different dependencies. Explain these differences and discuss the significance.
- Under what circumstances does the evaluation of conductivity spectra using the Cole-Cole model lose its meaningfulness? What alternative evaluation strategies are available?
- What are the benefits and limitations of the Cole-Cole model when inferring physicochemical processes in rocks from measurements of complex conductivity?