Underground Geophysical Practical Course

Spectral Induced Polarization

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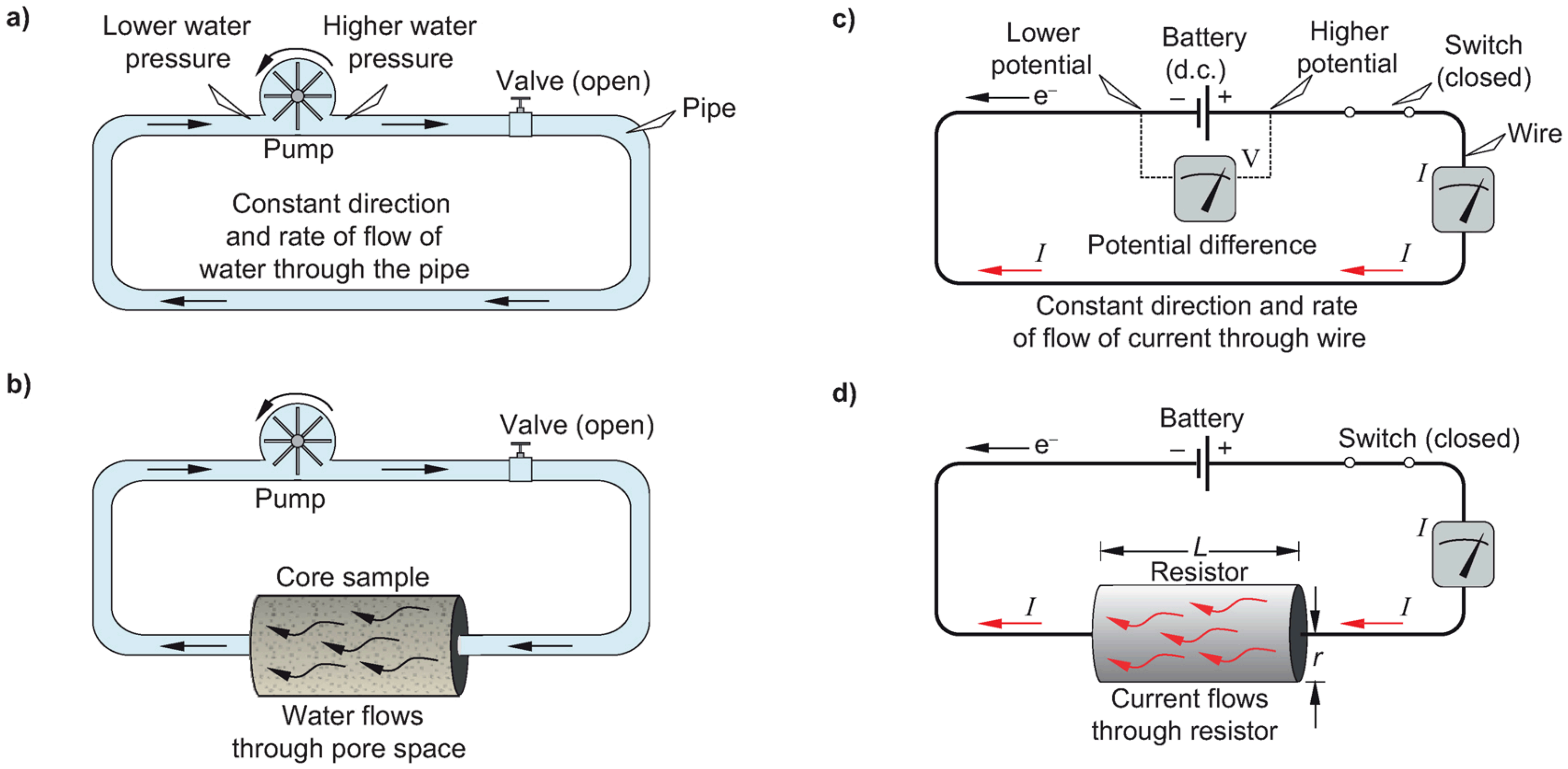
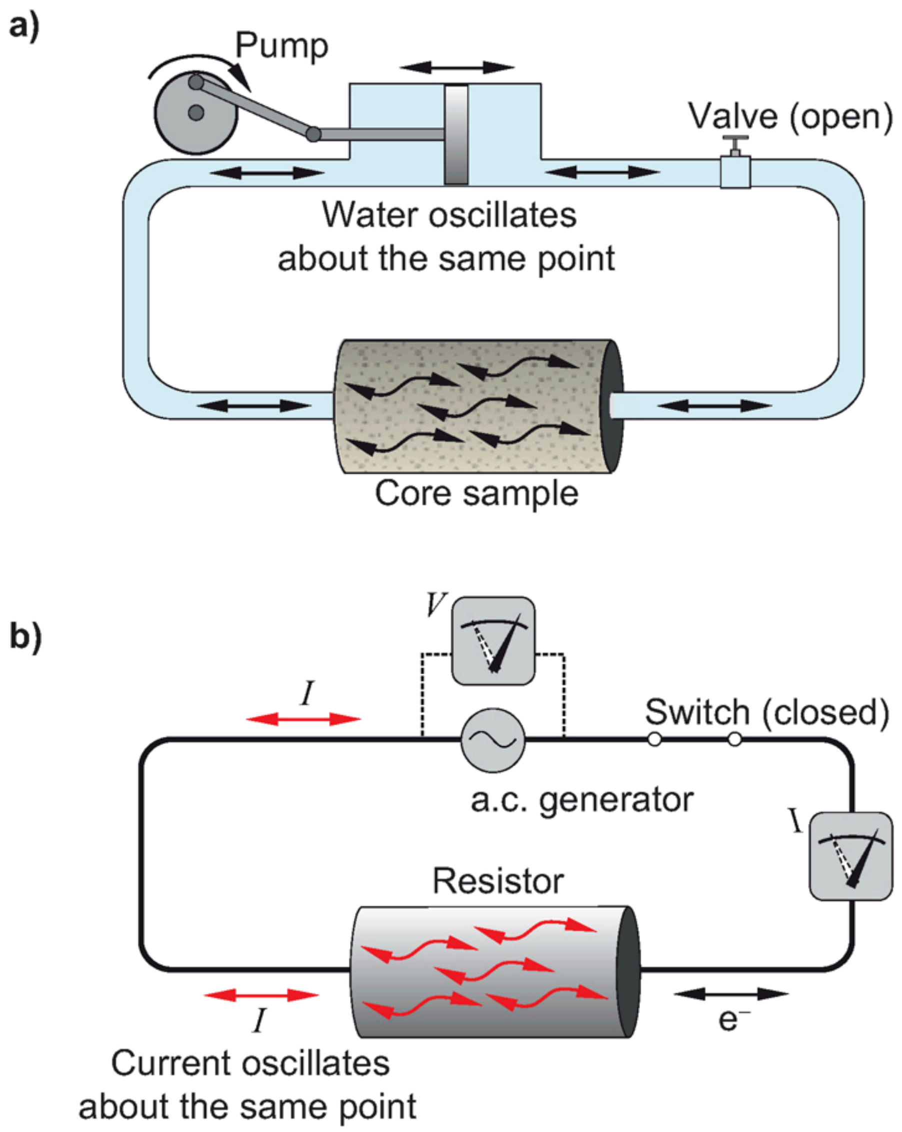
Induced Polarization (IP)

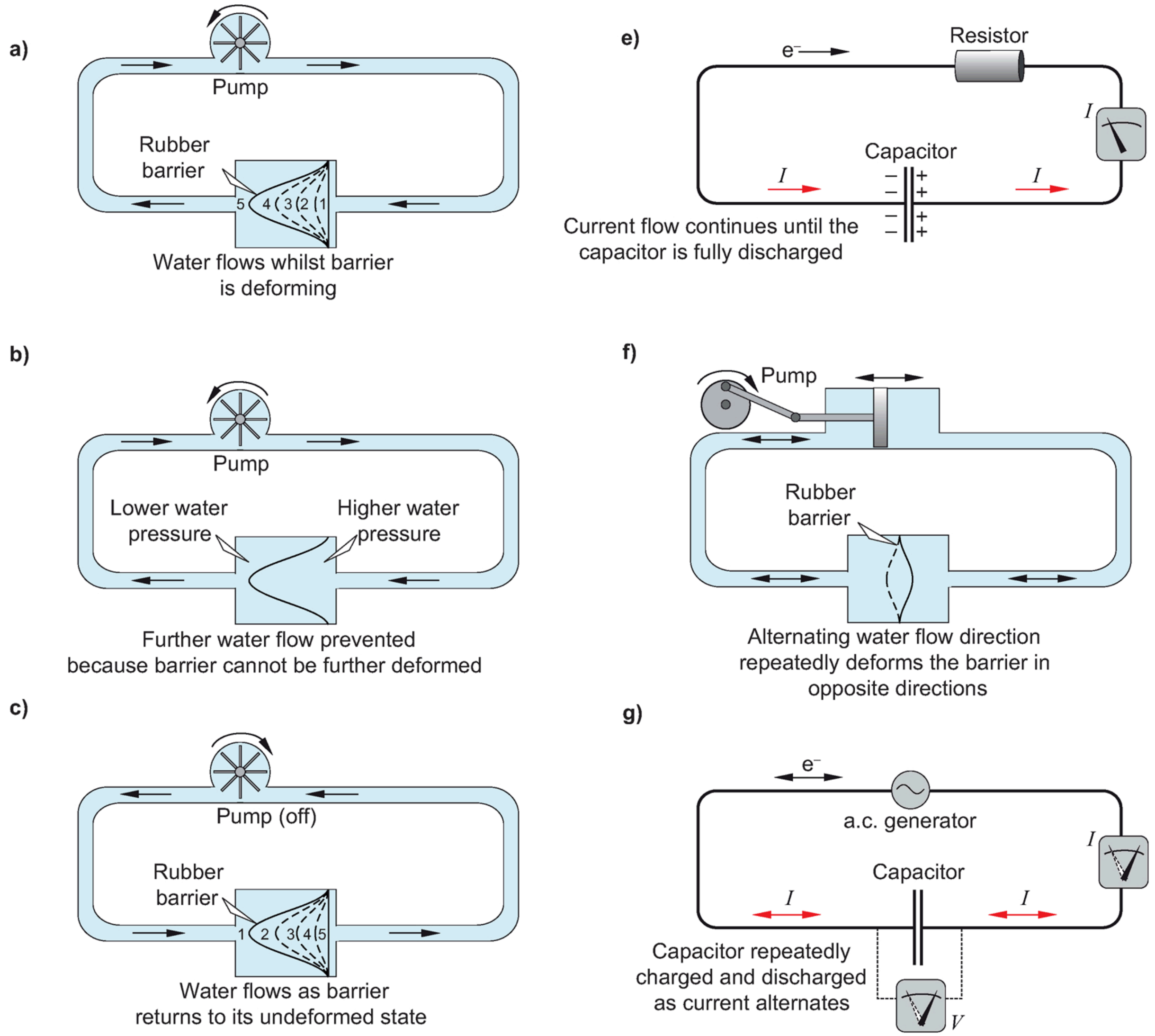
- increasing importance of ore deposits for raw material
- ore minerals (e.g. sulphides or oxides) often conductors
  - $\Rightarrow$ exploration with electromagnetic methods
- Schlumbergers (1930) & Dachnov (1941) observed chargeability
- Method of Induced Polarisation (Bleil, 1953)
  - traditional ore exploration with induced polarization
- conductivity & polarization mechanisms of ores largely unknown
- extracting probes and measuring cells hard $\Rightarrow$ in-situ

DC Equivalent (Dentith&Mudge, 2014)

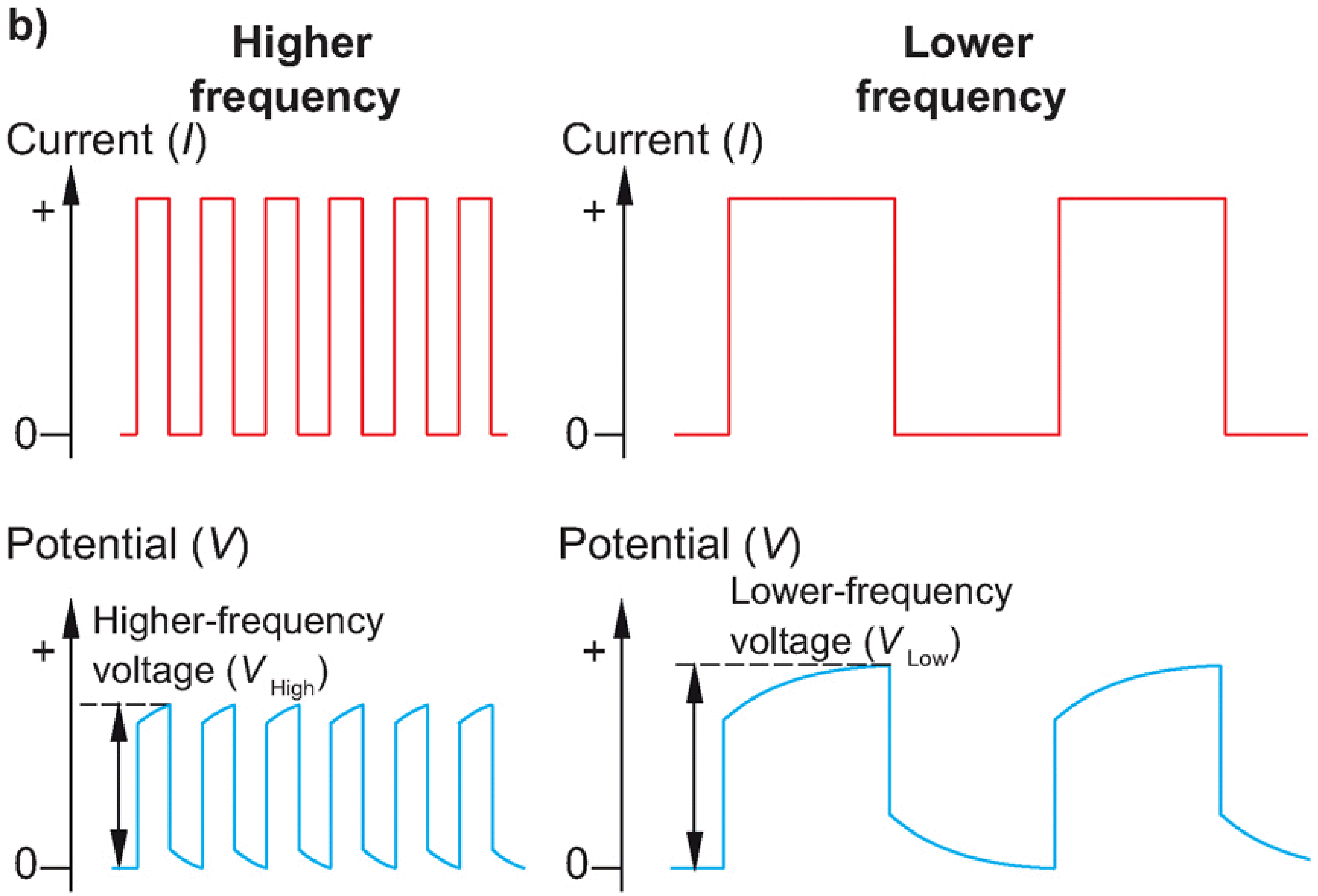


AC Equivalent (Dentith&Mudge, 2014)



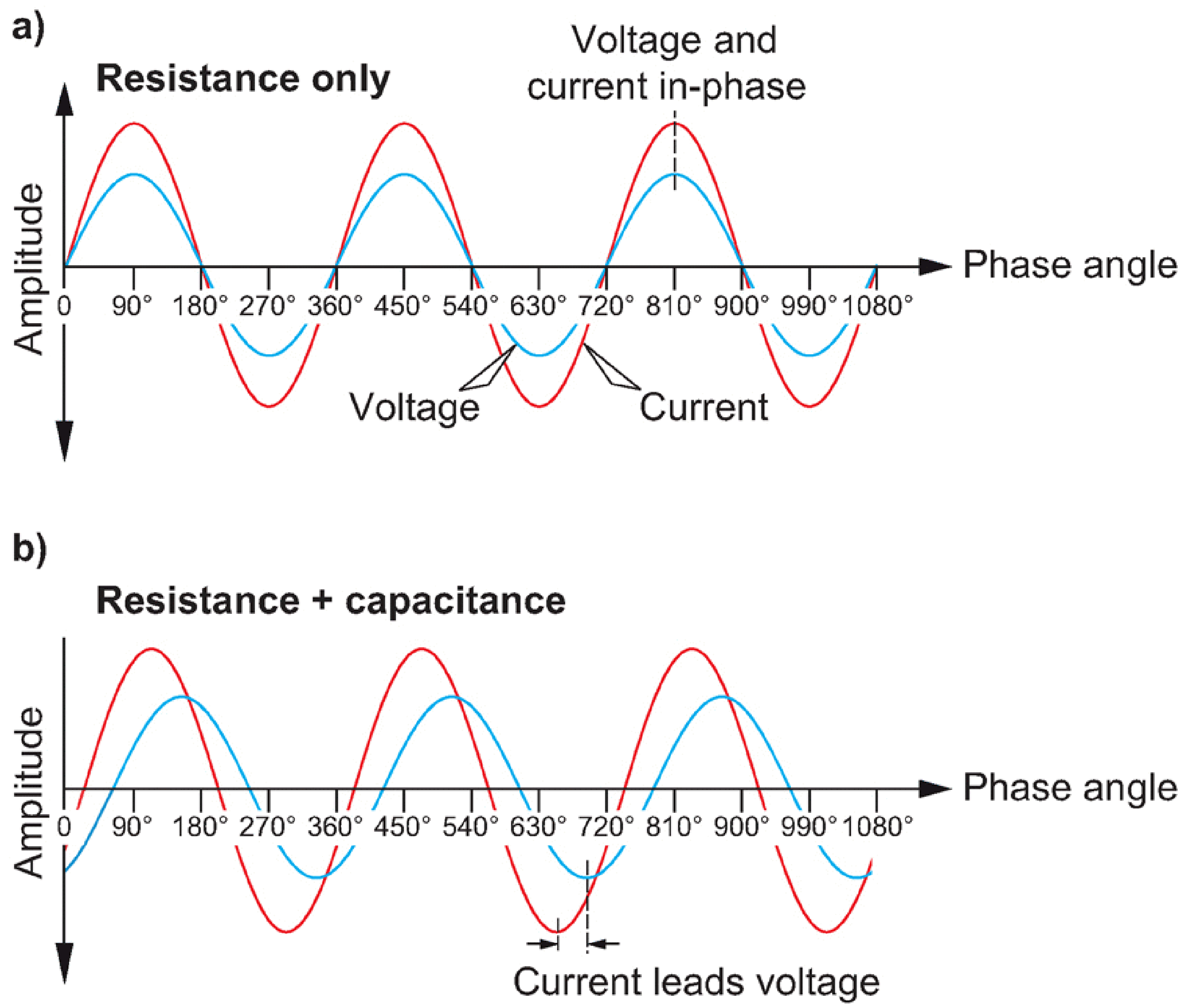


Time domain

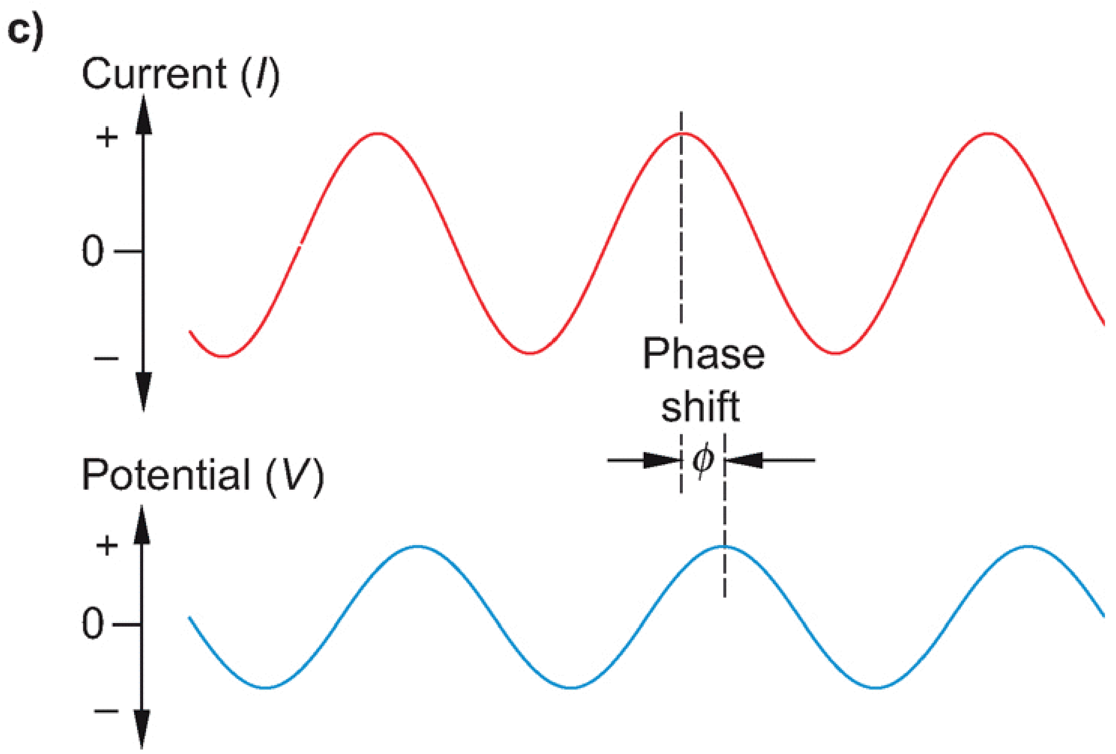


Dentith & Mudge (2014)

Frequency domain



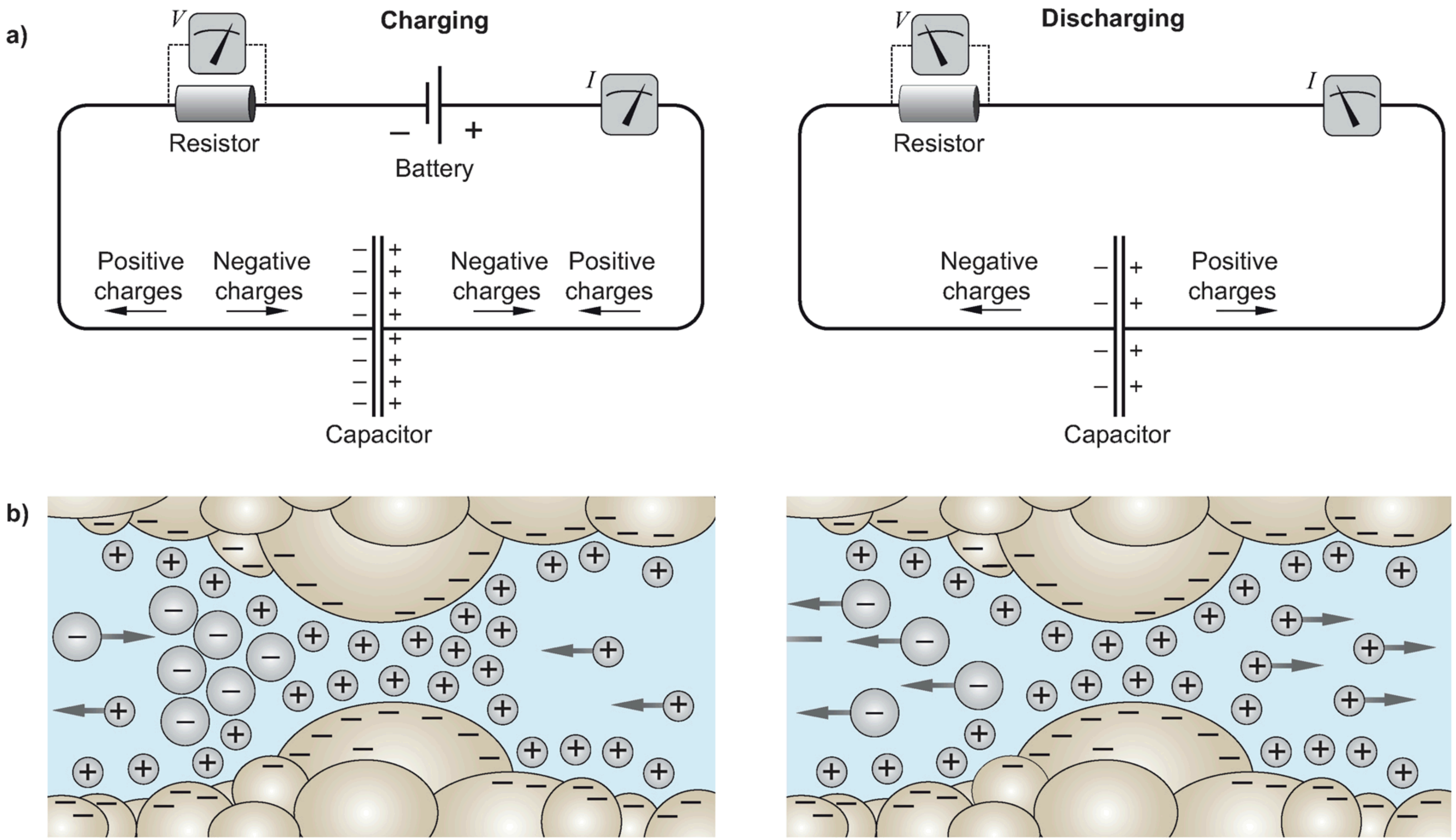
Phase shift



Dentith & Mudge (2014)

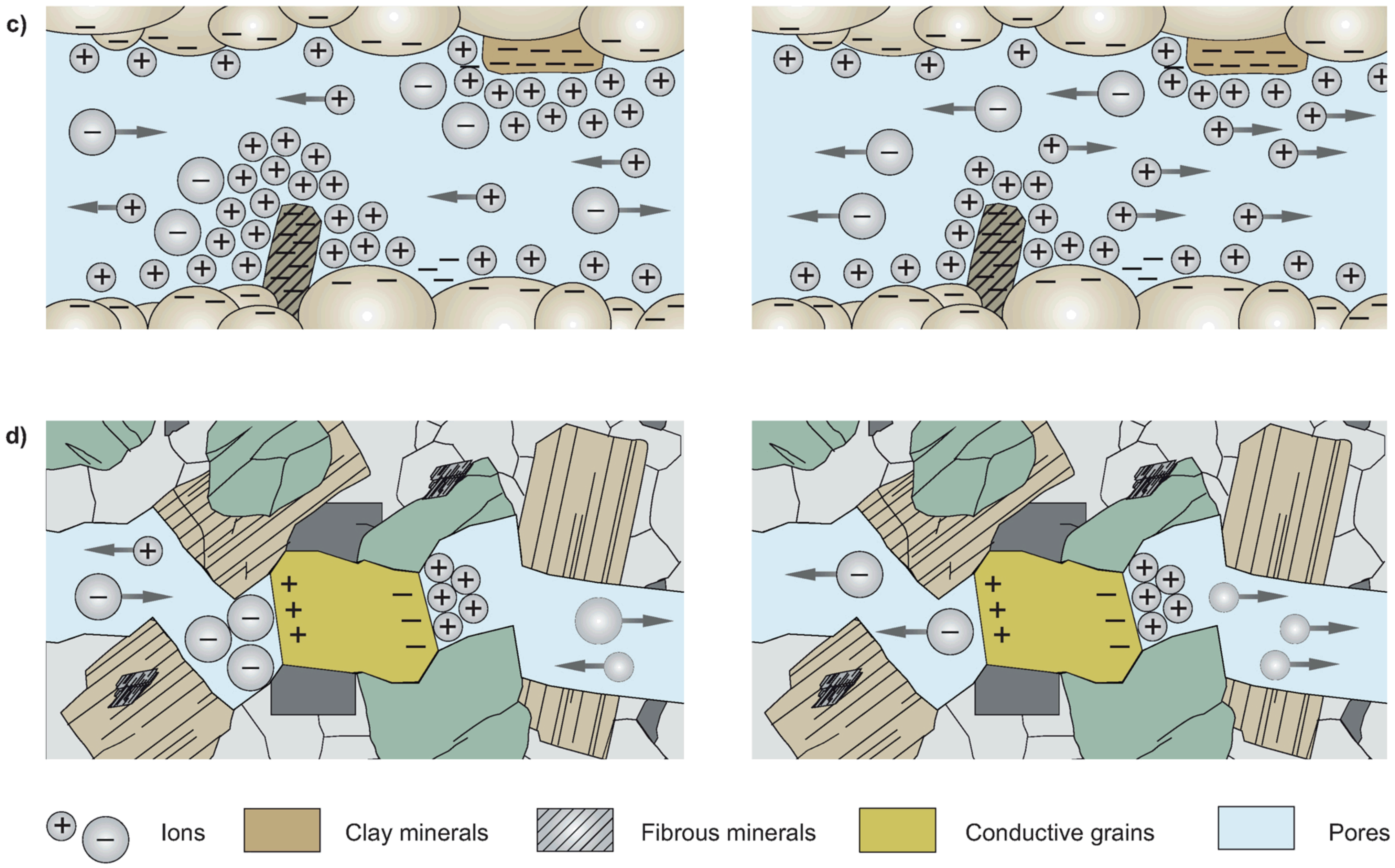
$$\sigma^* = \sigma' + \imath\sigma'' = |\sigma|e^{\imath\phi}$$

Membrane Polarisation

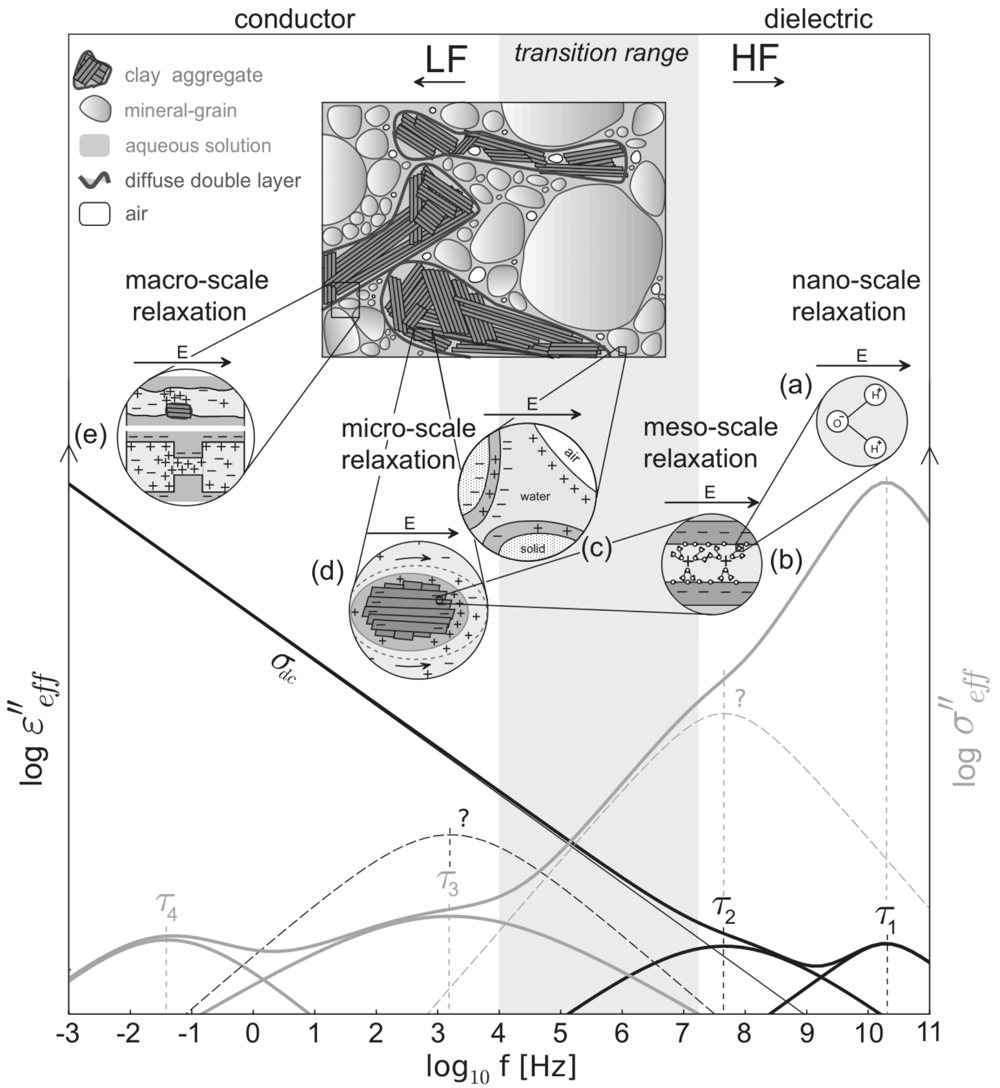


Dentith & Mudge (2014)

Polarisation



Relaxations



Loewer et al. (2017)

Debye relaxation

- fundamental polarisation

$$\sigma(\omega) = \sigma_\infty + (\sigma_0 - \sigma_\infty)\frac{m}{\imath\omega\tau}$$

- exponential decay

$$U(t) = U_0 m e^{-t/\tau}$$

Debye and Cole-Cole models

superposition of multiple decays

$$\rho^*(\omega) = \rho_0 \left(1 - \sum_{k=1}^{K} m_k \left(1 - \frac{1}{1 + \imath\omega\tau_k}\right)\right)$$

relaxation width: Cole-Cole

$$\rho^*(\omega) = \rho^0 \left[1 - m \left(1 - \frac{1}{1 + (\imath\omega\tau)^c}\right)\right]$$

Kramers-Kronig relations

Connect real und imaginary part of analytic functions

$$\rho''(\omega) = \frac{2\omega}{\pi} \int_0^\infty \frac{\rho'(x) - \rho'(\omega)}{x^2 - \omega^2} \mathrm{d}x$$

$$\rho'(\omega) = \rho'(\infty) + \frac{2}{\pi} \int_0^\infty \frac{x\rho''(x) - \omega\rho''(\omega)}{x^2 - \omega^2} \mathrm{d}x$$

Measurement: SIP device

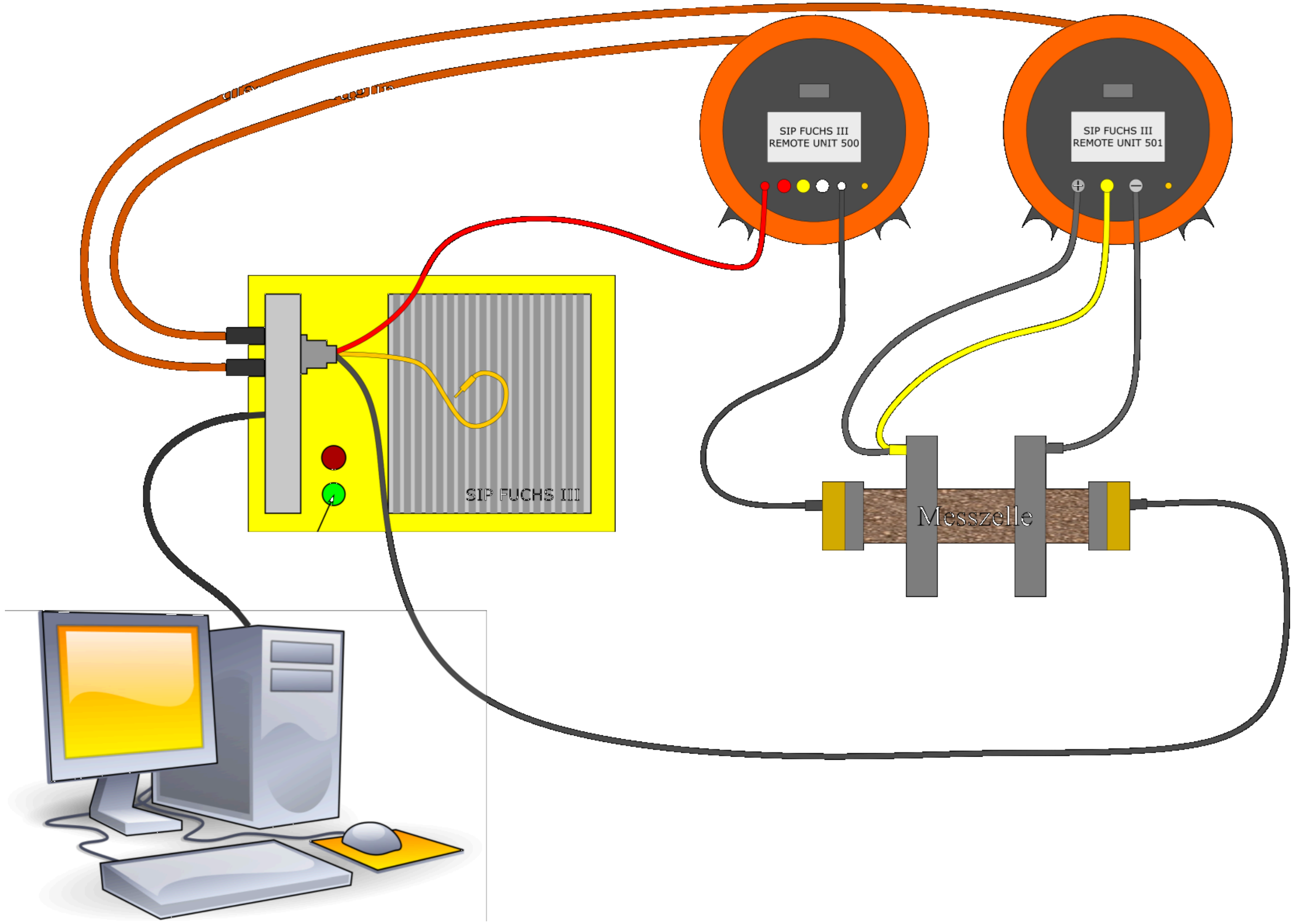
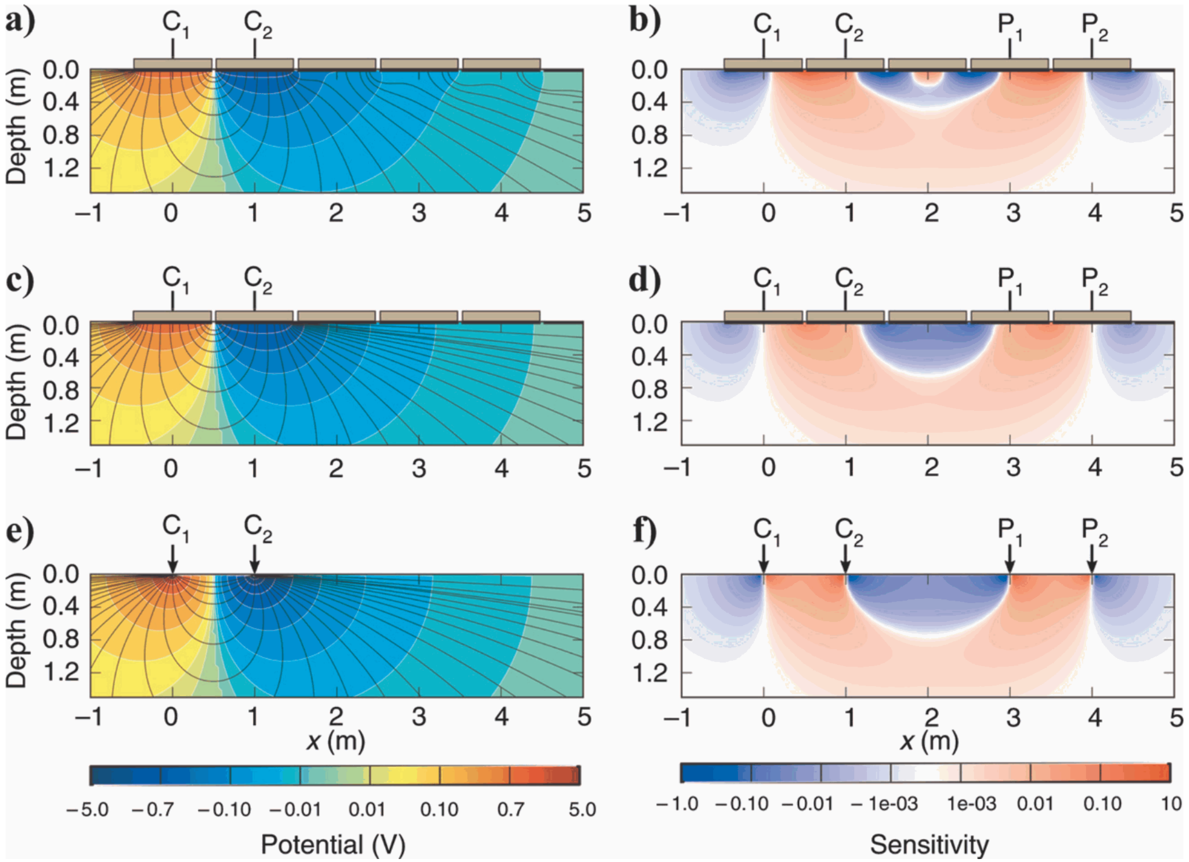
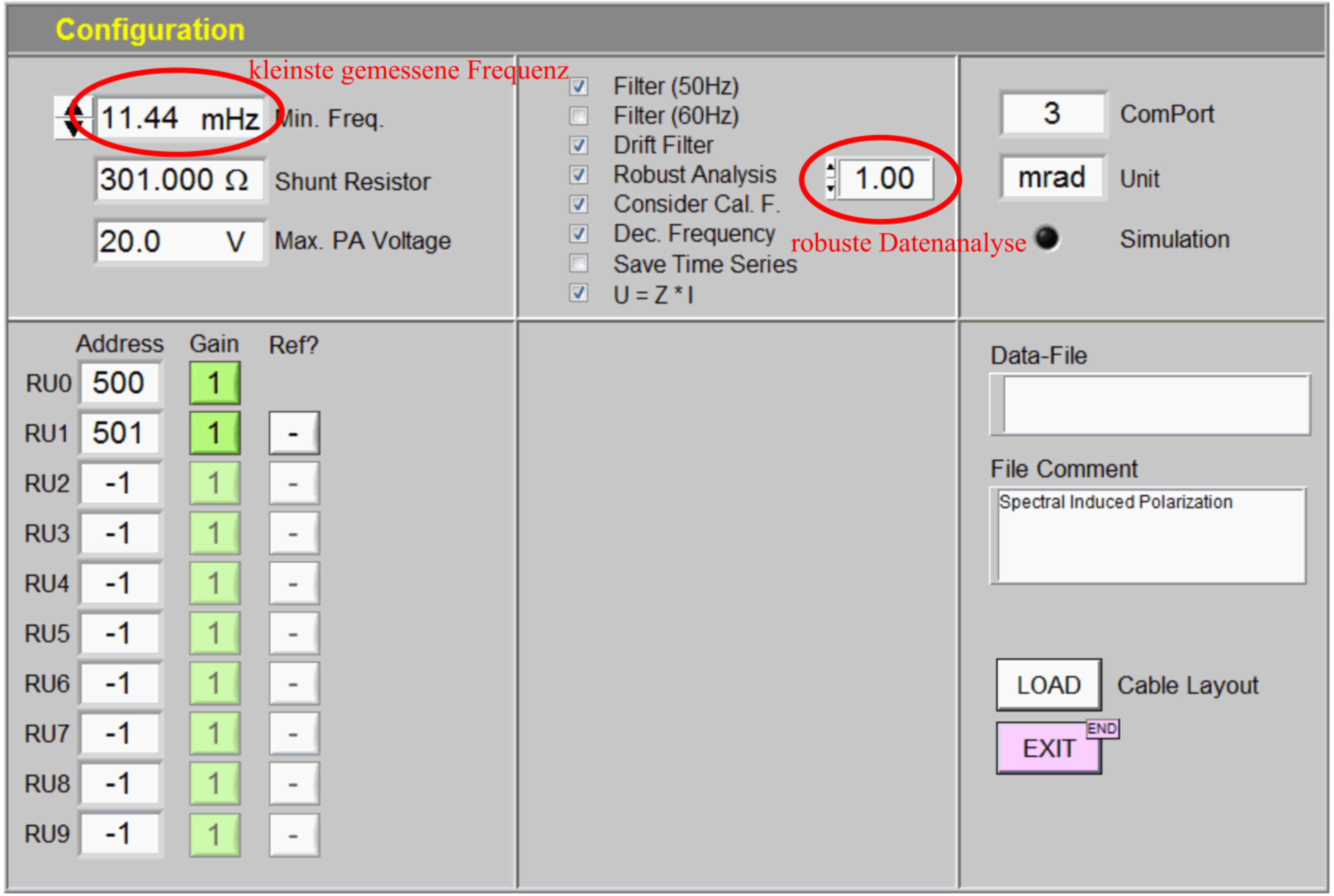


Plate electrodes (Rücker & Günther, 2011)

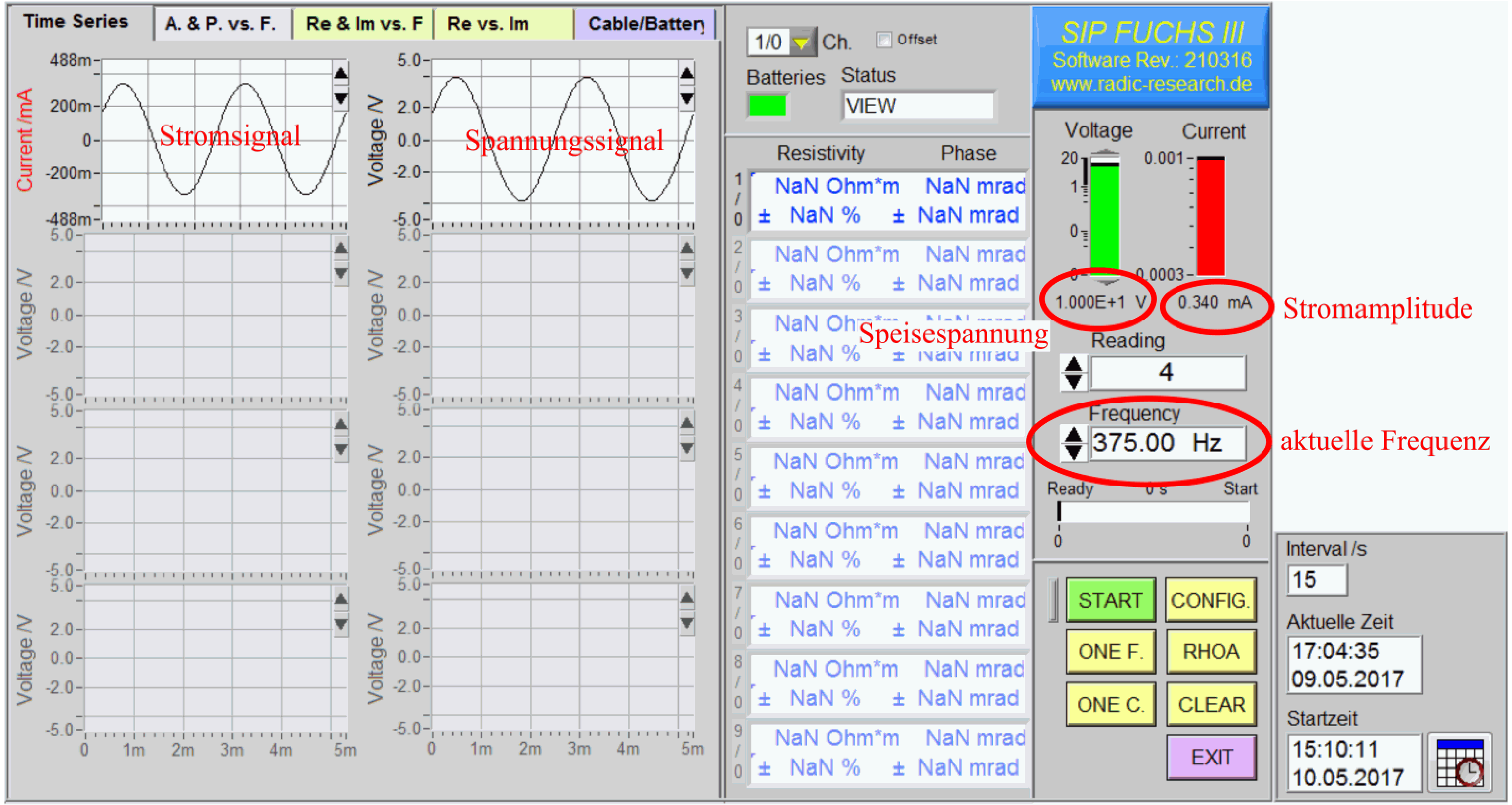


- Wenner array (AMNB)
- constant spacing a
- geometric factor $k = 4\pi a$
- EKG electrodes
- point vs. plate electrodes
- deformed potential & current
- slightly changed sensitivity

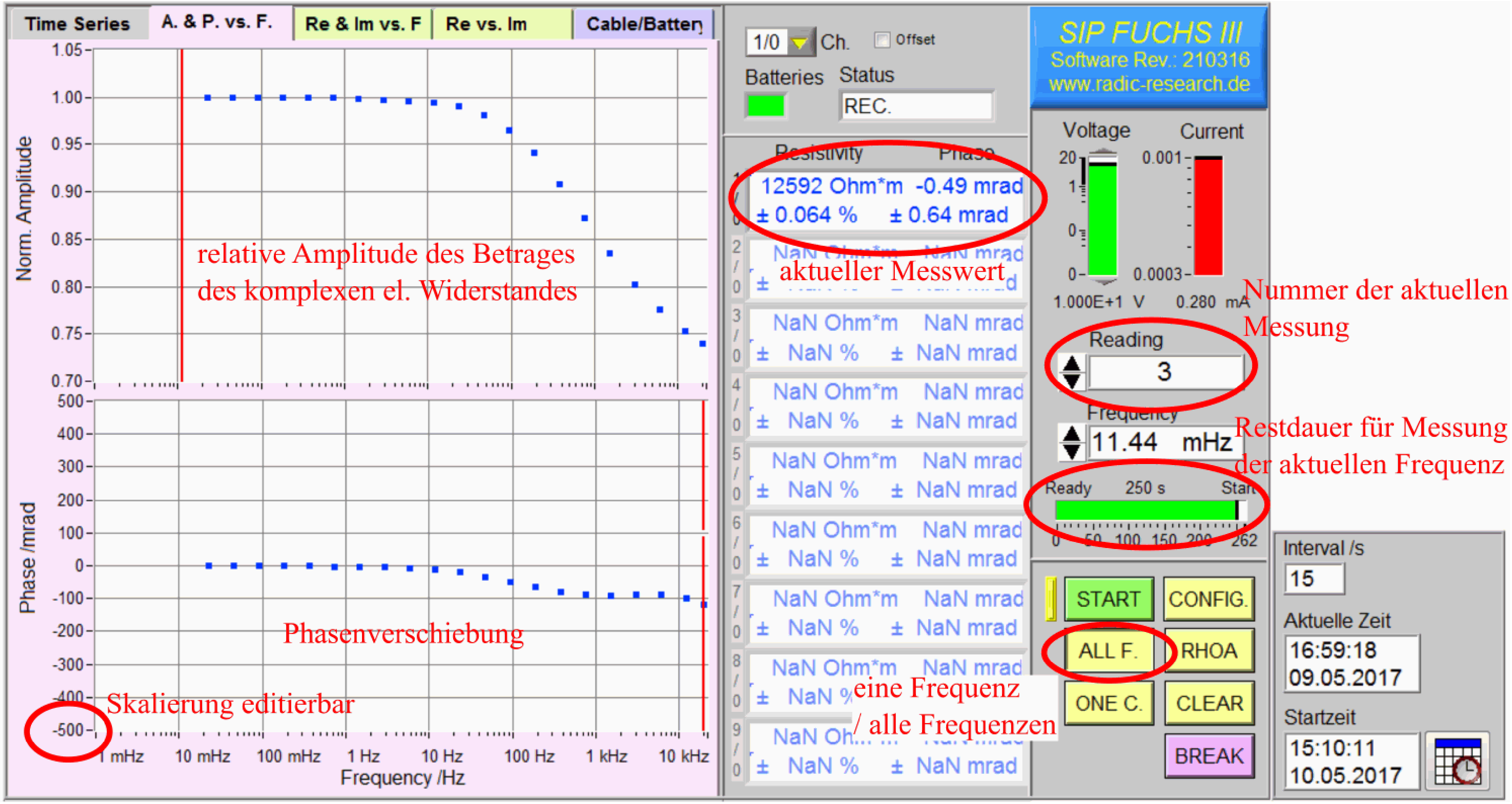
SIP measurement



SIP measurement



SIP measurement



Data analysis

Python

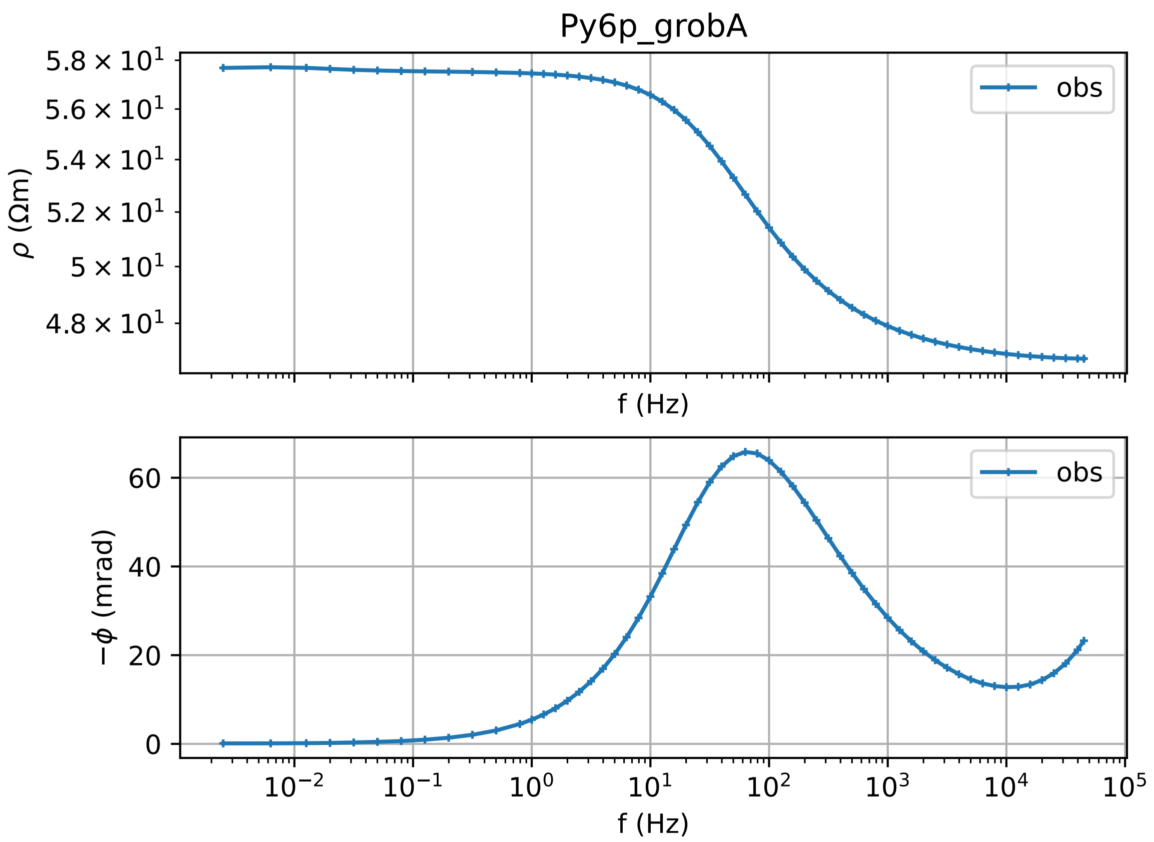
- make use of pyGIMLi package
- `conda create -n pg -c gimli -c conda-forge` or
- `pip install pygimli`
- make use of class `SIPSpectrum`

Data analysis: raw data

```python
spec = SIPSpectrum("example.res", k=k)
print(spec)
spec.showData()
```

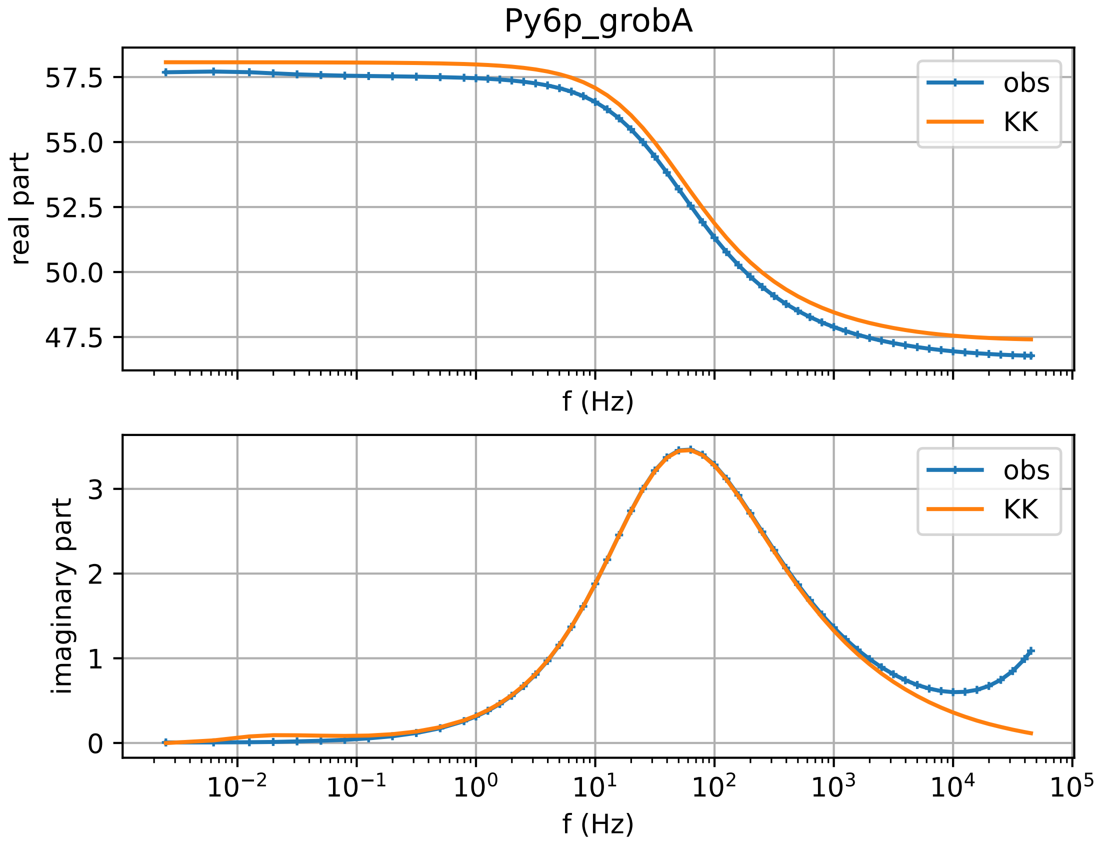
```
SIPSpectrum object
nf=60 min/max=0.002512/45000.0
```

```
(<Figure size 640x480 with 2 Axes>,
 array([<Axes: title={'center': 'Py6p_grobA'},
xlabel='f (Hz)', ylabel='$\\rho$
($\\Omega$m)'>,
        <Axes: xlabel='f (Hz)', ylabel='$-
\\phi$ (mrad)'>], dtype=object))
```



Data analysis: check Kramers-Kronig

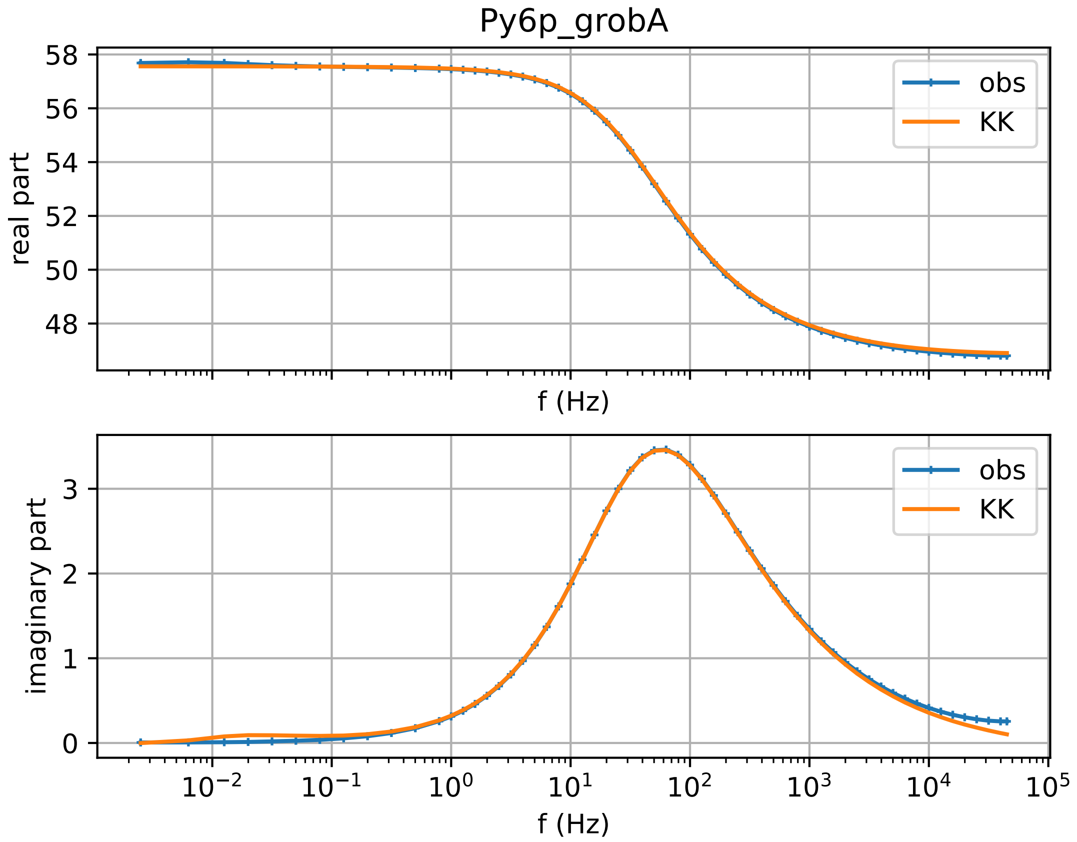
```python
spec = SIPSpectrum("example.res")
fig, ax = spec.showDataKK()
fig.savefig("corrKK.svg")
```



Data analysis: coupling removal

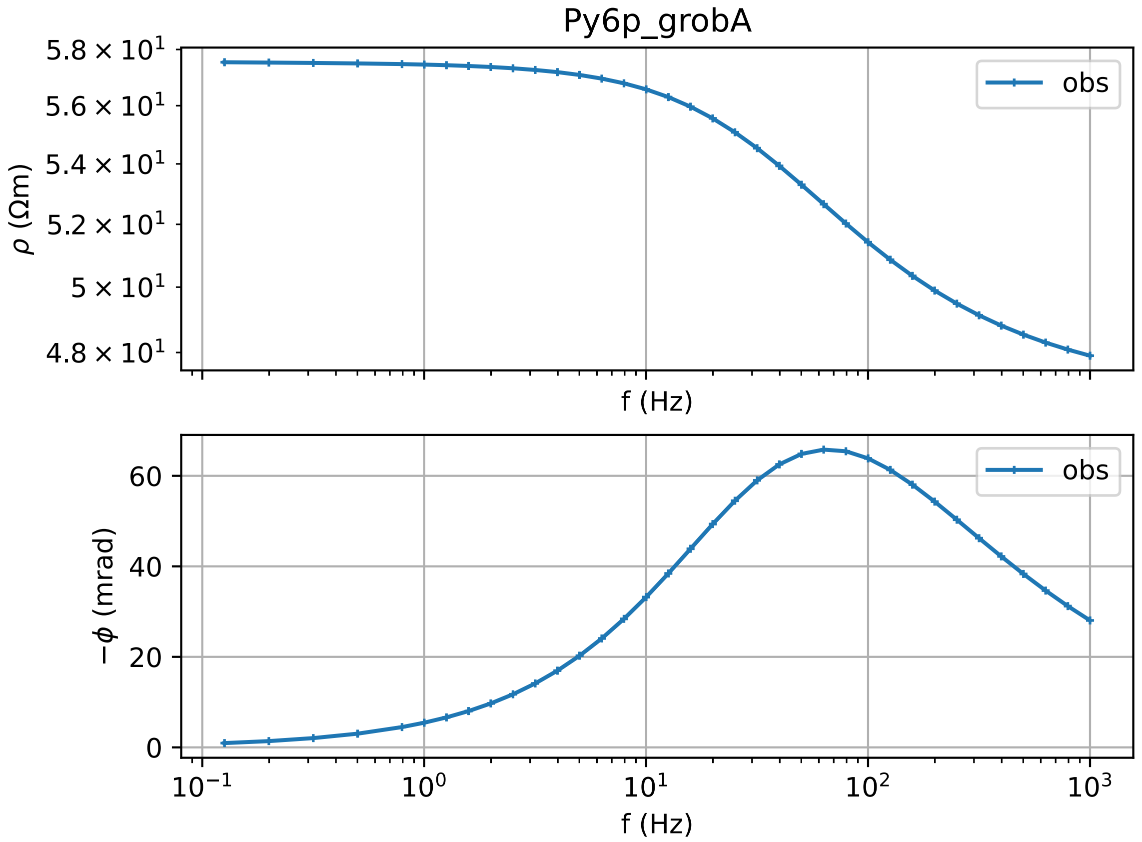
```
spec = SIPSpectrum("example.res")
spec.removeEpsilonEffect()
fig, ax = spec.showDataKK()
```

- reliable data: f=100mHz-1kHz



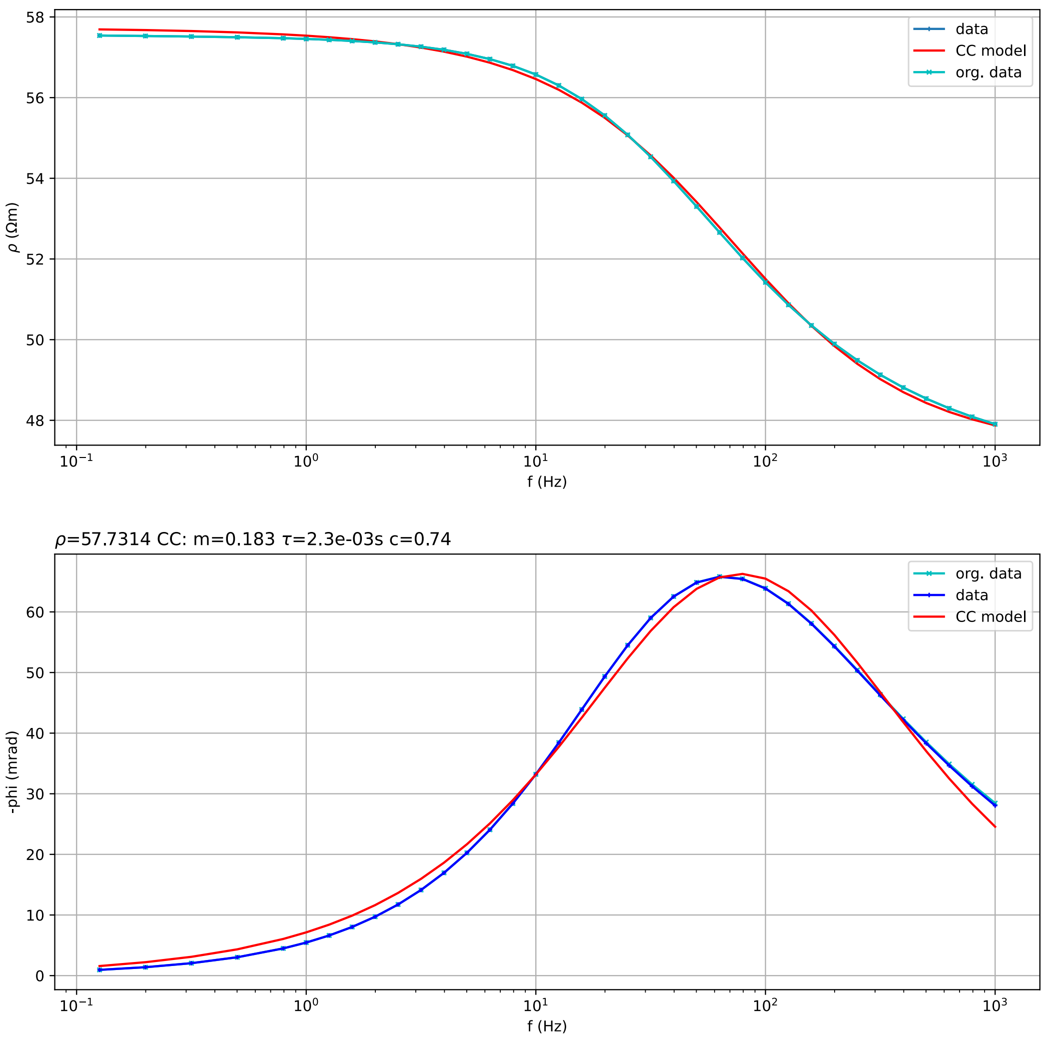
Data analysis: filter

```
spec = SIPSpectrum("example.res")
spec.removeEpsilonEffect()
fig, ax = spec.showDataKK()
spec.cutF(1000.0)
spec.cutF(0.1, down=True)
fig, ax = spec.showData()
```



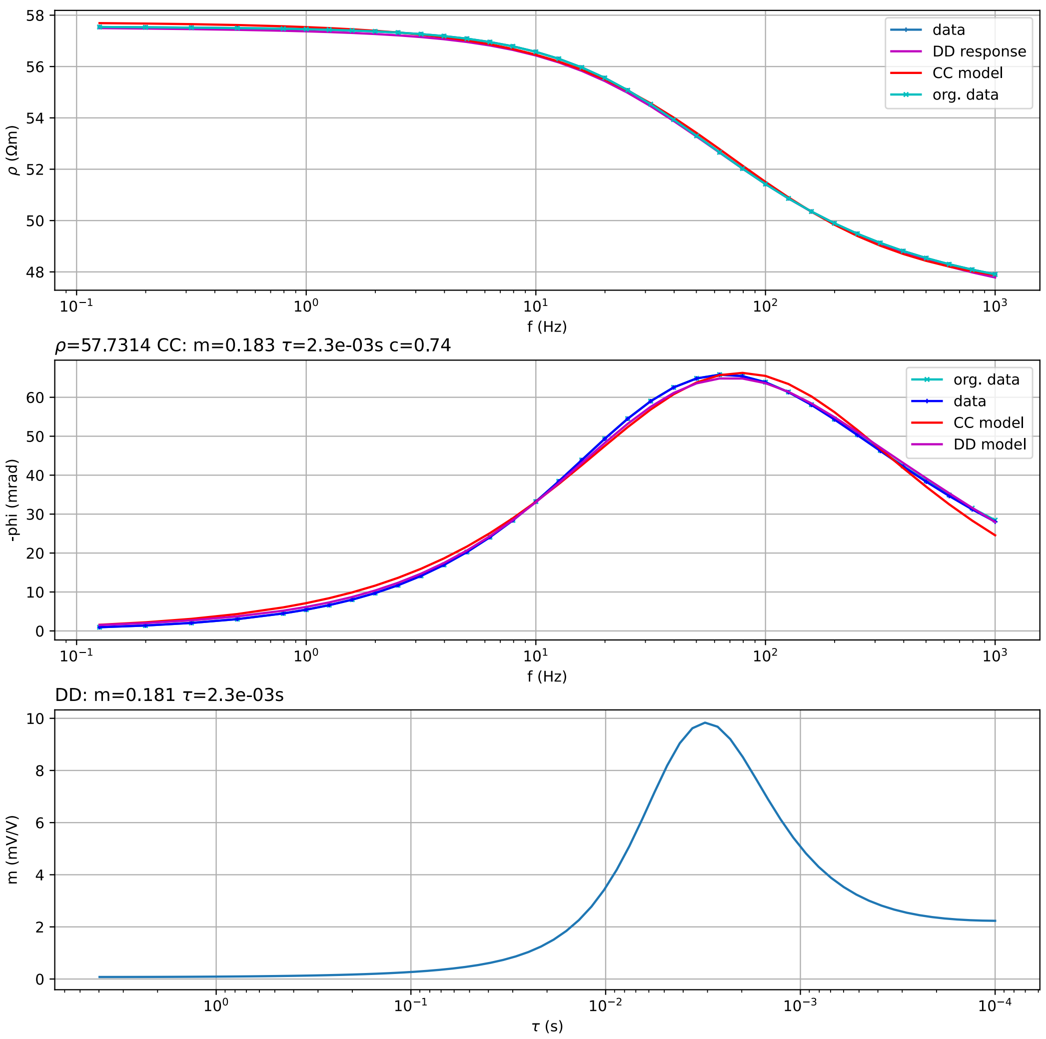
Data analysis: fit Cole-Cole

```
spec = SIPSpectrum("example.res")
spec.removeEpsilonEffect()
fig, ax = spec.showDataKK()
spec.cutF(1000.0)
spec.cutF(0.1, down=True)
spec.fitColeCole()
fig, ax = spec.showAll()
```



Data analysis: Debye decomposition

```python
spec = SIPSpectrum("example.res")
spec.removeEpsilonEffect()
fig, ax = spec.showDataKK()
spec.cutF(1000.0)
spec.cutF(0.1, down=True)
spec.fitColeCole()
spec.fitDebyeModel()
fig, ax = spec.showAll()
```



Report

1. Compute geometric factor for used array
2. Load the data and plot them using `SIPSpectrum`
3. Process (check KK, filter) the data
4. Fit Cole & Debye models
5. Repeat for all measured rock types
6. Interpret the results
7. Discuss possible error sources
8. Evaluate applicability of the method & improvements

Further reading

- Course material DC resistivity & Electromagnetics methods (in German), including induced polarization
- Dentith M and Mudge ST (2014): Geophysics for the mineral exploration geoscientist. Cambridge University Press
- pyGIMLi website, specifically examples on IP
- Rücker, C. & Günther, T. (2011): The simulation of Finite ERT electrodes using the complete electrode model. Geophysics 76(4), F227-238, doi:10.1190/1.3581356.