

## — EISART —

File Browser Settings Terminal

File Settings DRT Settings

Save Format txt

Data to save

- ☒ Convert \*.ism
- ☒ Save plots
- ☒ Save ref. DRT or smoothed EIS
- ☒ Save EIS&DRT of ECM
- ☒ Save weights
- ☒ Save residuals

Batch Settings

- ☒ Plot each
- ☒ Save data

Start B

Plot Settings ECM Settings Manual Peak

Model

Load

Save

Auto

Parameters

Peak 3 / 6 : OE reac FE ☒ G ☐ Fix

tau from 1.85e-03 s to 1.38e-02 s

alpha from 0.40 to 1.00

↑AZ ↓ZA



Save Data

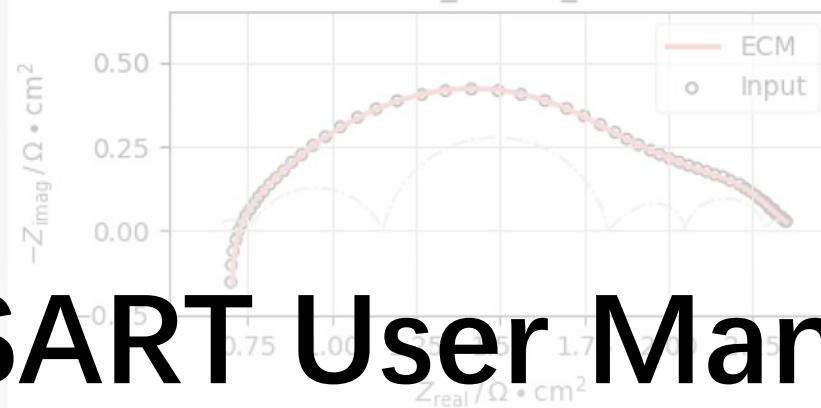
Refresh Plot

Active cell area

0.4 cm<sup>2</sup>

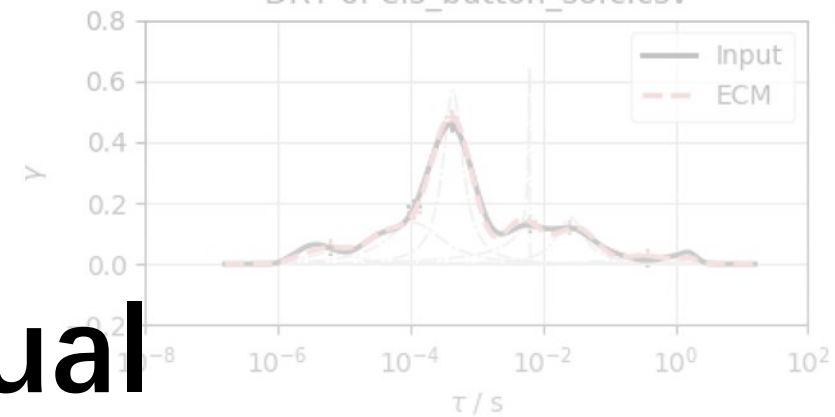
Active electrode or electrolyte area, whichever is smaller

EIS of eis\_button\_soft.csv



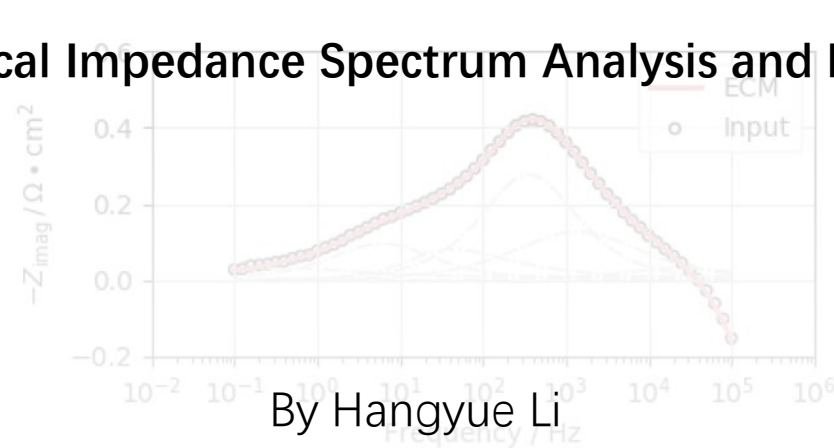
## — EISART —

DRT of eis\_button\_soft.csv



## EISART User Manual

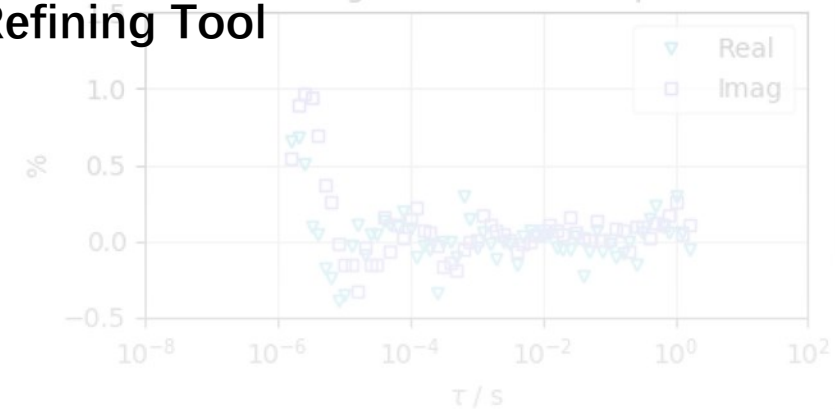
Electrochemical Impedance Spectrum Analysis and Refining Tool



By Hangyue Li

Version 2.5 on January 28<sup>th</sup>, 2022

Fitting Residual from Input



Done.

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### 2.1 File and DRT Settings

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EISART is a fast impedance spectrum analysis tool originally developed for solid oxide fuel cells.

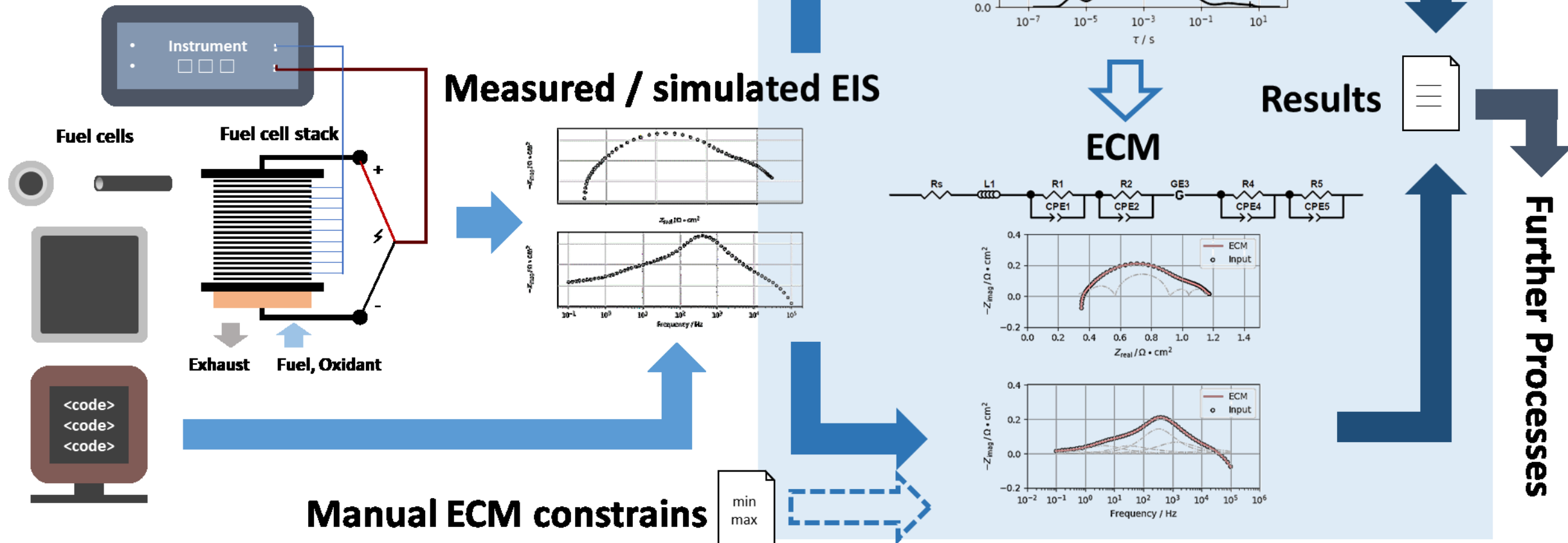
It features one-click operations for:

- Distribution of Relaxation Time (DRT) analysis
- Auto or semi-auto Equivalent Circuit Model (ECM) fitting & ZView \*.mdl model importing/exporting
- Batch processing and easy-to-use saving format

EISART is robust to noise, wiring induction, and deviated data points in EIS. It visualizes the original data and the fitting result as Nyquist and Bode plots, and shows the fitting residuals to the user in real time.

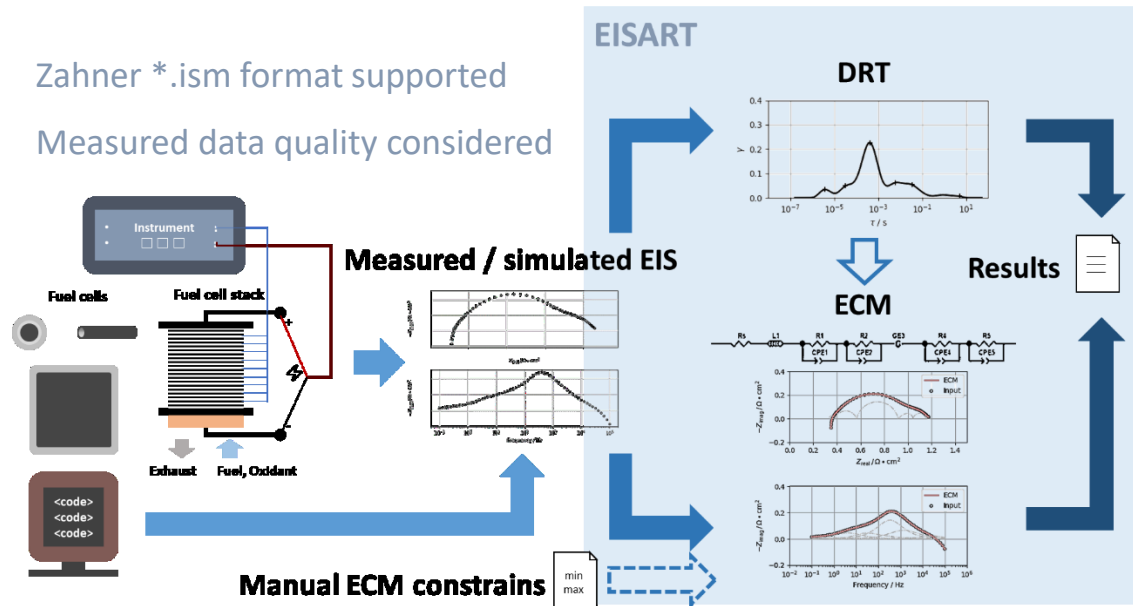
# 1 Introduction

## 1.1 Functionality



# 1 Introduction

## 1.1 Functionality



EISART is a fast impedance spectrum analysis tool originally developed for solid oxide **fuel cells**.

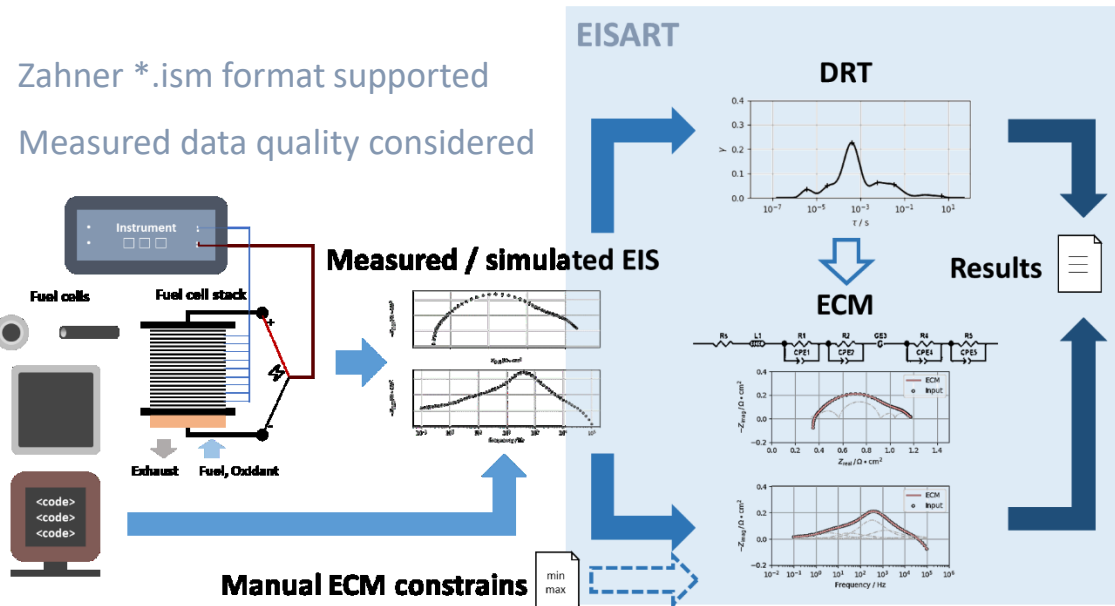
It features **one-click** operations for:

- Distribution of Relaxation Time (**DRT**) analysis
- Auto or semi-auto Equivalent Circuit Model (**ECM**) fitting & **ZView** \*.mdl model importing/exporting
- **Batch** processing and easy-to-use saving format

EISART is **robust to noise, wiring induction, and deviated data points** in EIS. It visualizes the original data and the fitting result as Nyquist and Bode plots, and shows the fitting residuals to the user in real time.

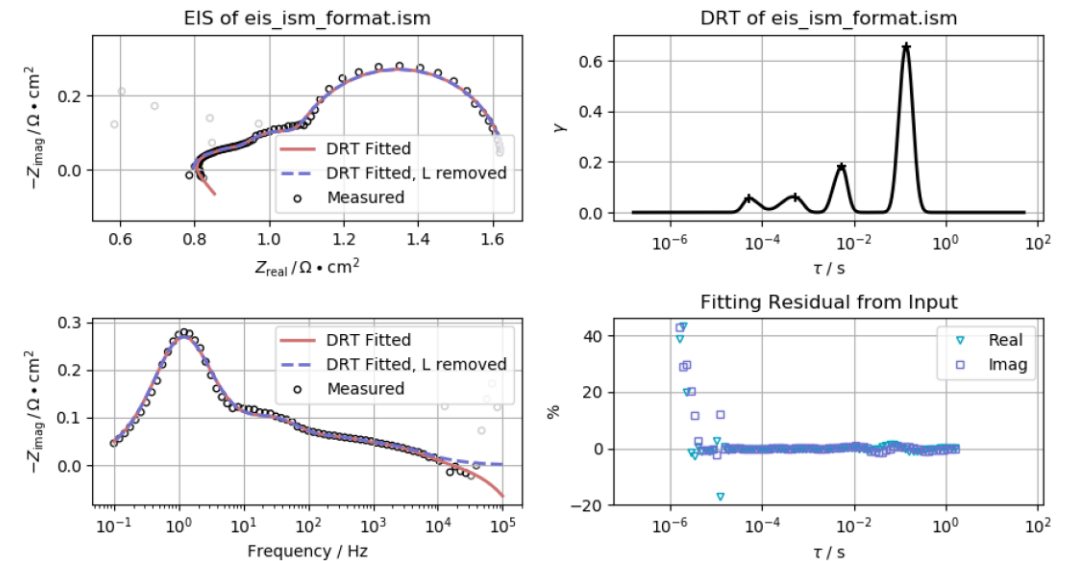
# 1 Introduction

## 1.1 Functionality



EISART may downweigh an input data point if it considers the point deviated. **The weights are shown in opacity** in the Nyquist and Bode plots.

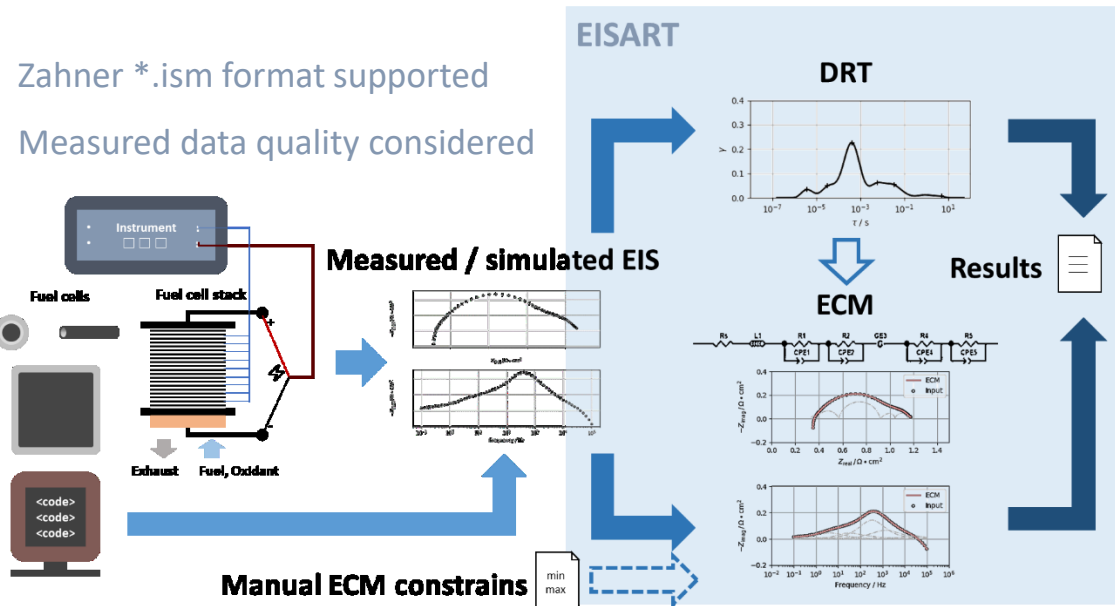
DRT analysis and ECM fitting are based on weighted input EIS data, in order to minimize the impact of noise and individual deviated points.



K-K Test Mode off, DRT plot to  $\tau$

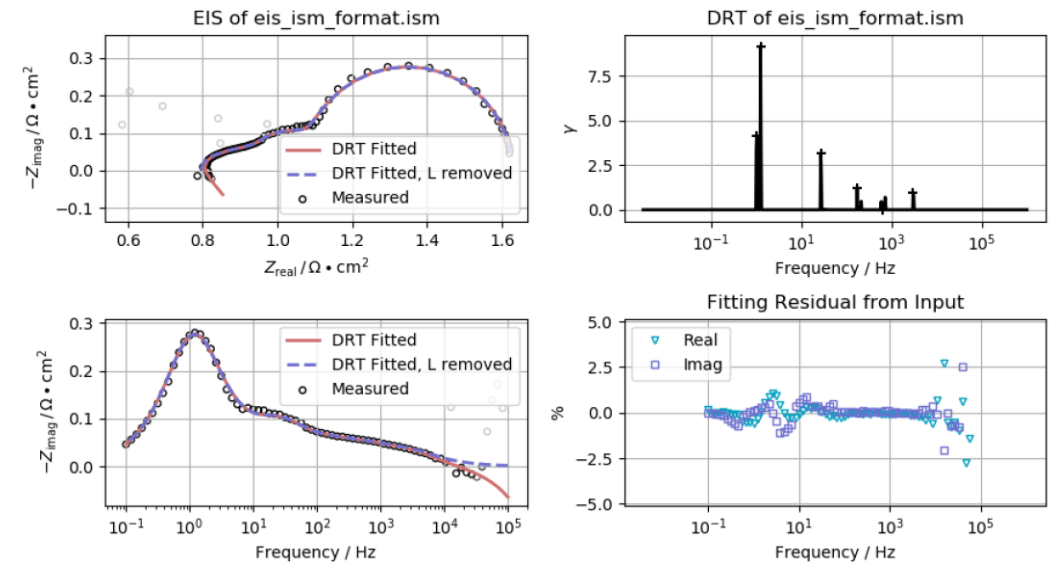
# 1 Introduction

## 1.1 Functionality



For DRT analyzing, EISART offers **K-K Test** (Krämers-Krönig Test) mode, in which the user may check the quality of input EIS data and whether the non-negative- $\gamma$  DRT analysis in EISART suits the input EIS.

The **DRT** result may be plotted to **relaxation time  $\tau$**  or **eigen frequency  $f = 1/(2\pi\tau)$** .



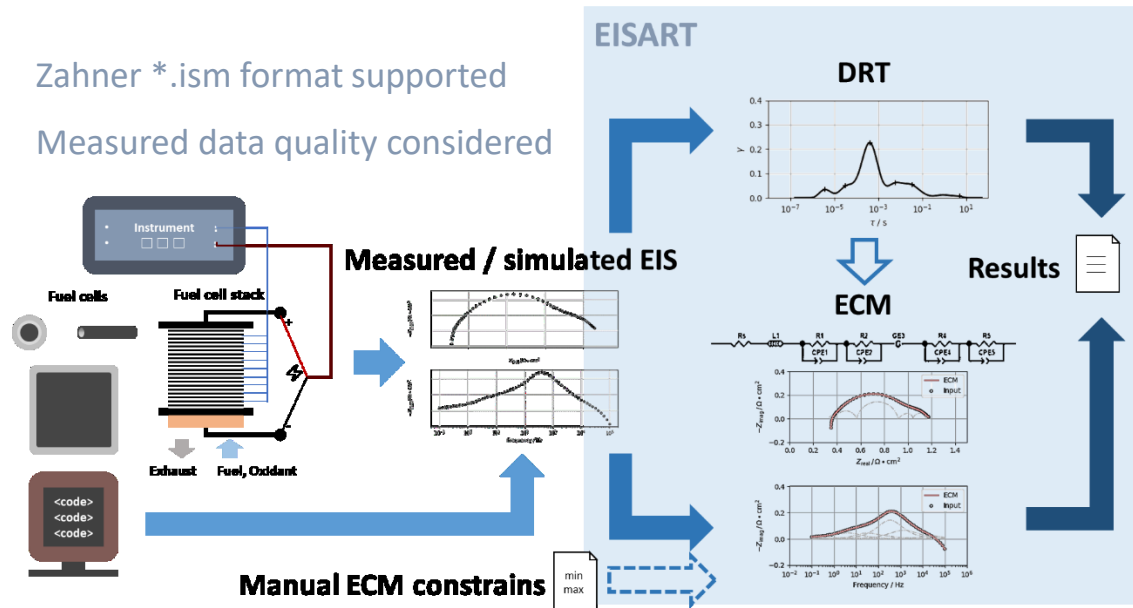
K-K Test Mode on, DRT plot to frequency

# 1 Introduction

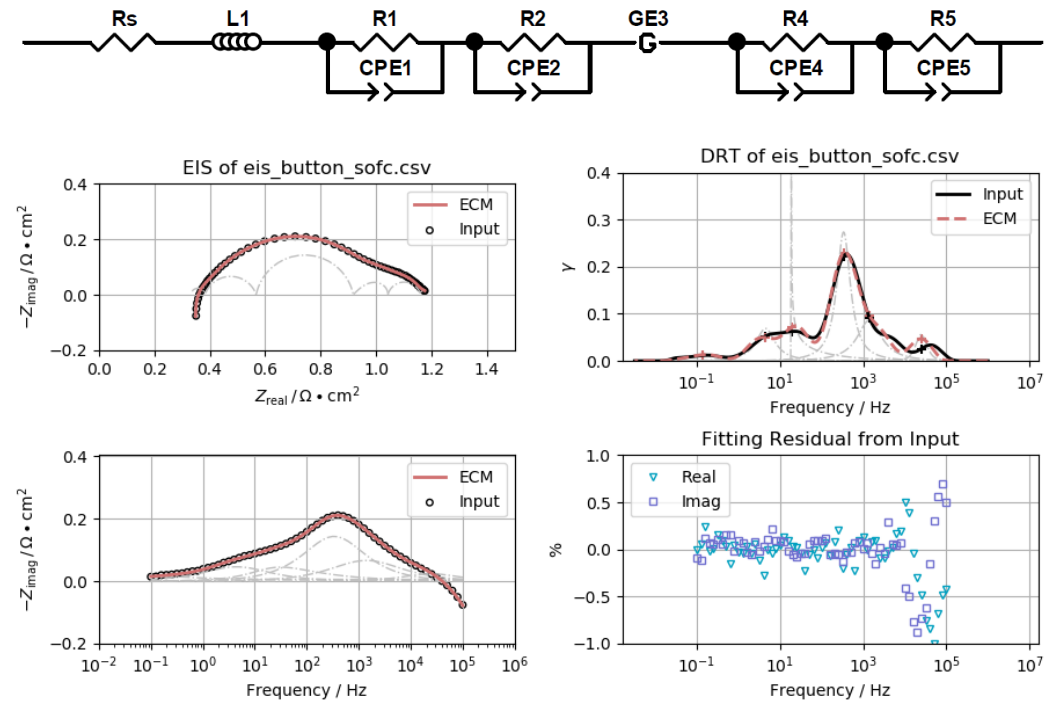
## 1.1 Functionality

Zahner \*.ism format supported

Measured data quality considered

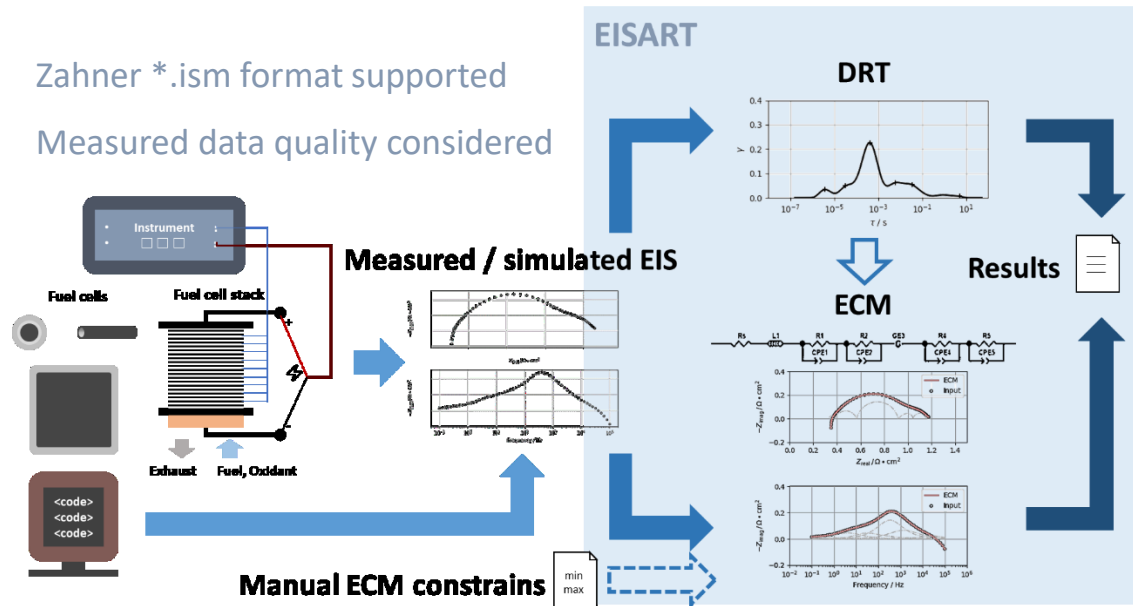


For ECM fitting, EISART supports any circuit comprising **RQ/RC elements, Gerischers, resistors, and inductors.**



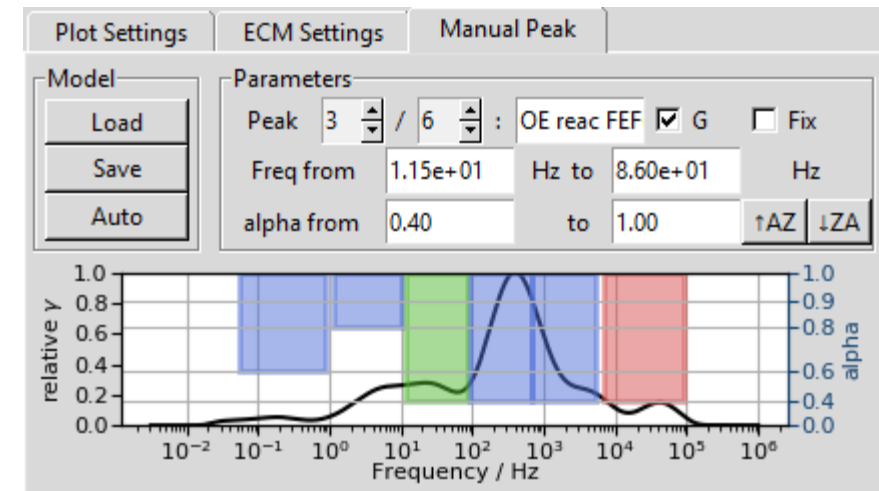
# 1 Introduction

## 1.1 Functionality



EISART allows its user to **leave the fitting entirely to the program**, or fit **semi-automatically** by manually specify the constrains to ECM parameters. ECM constrains may be saved as file or loaded from file. Loading Zview \*.mdl models supported.

For **ECM with constrains**, the number of RQ/RC elements or Gerischers ranges from 1 to 20.

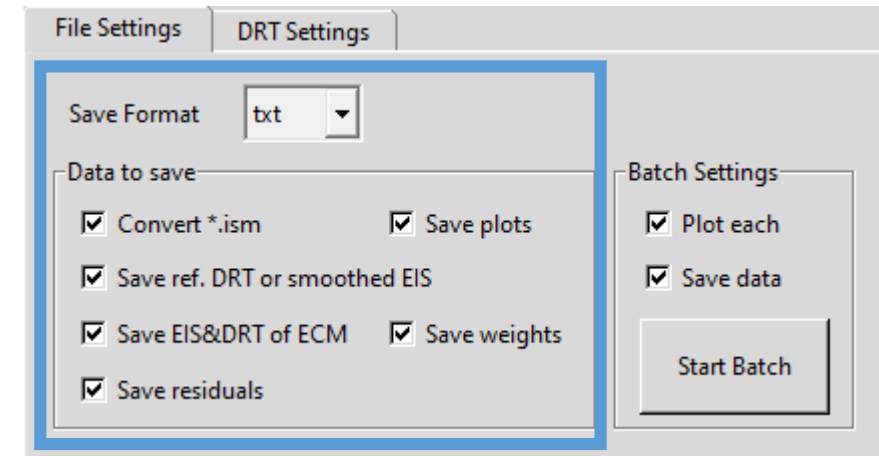
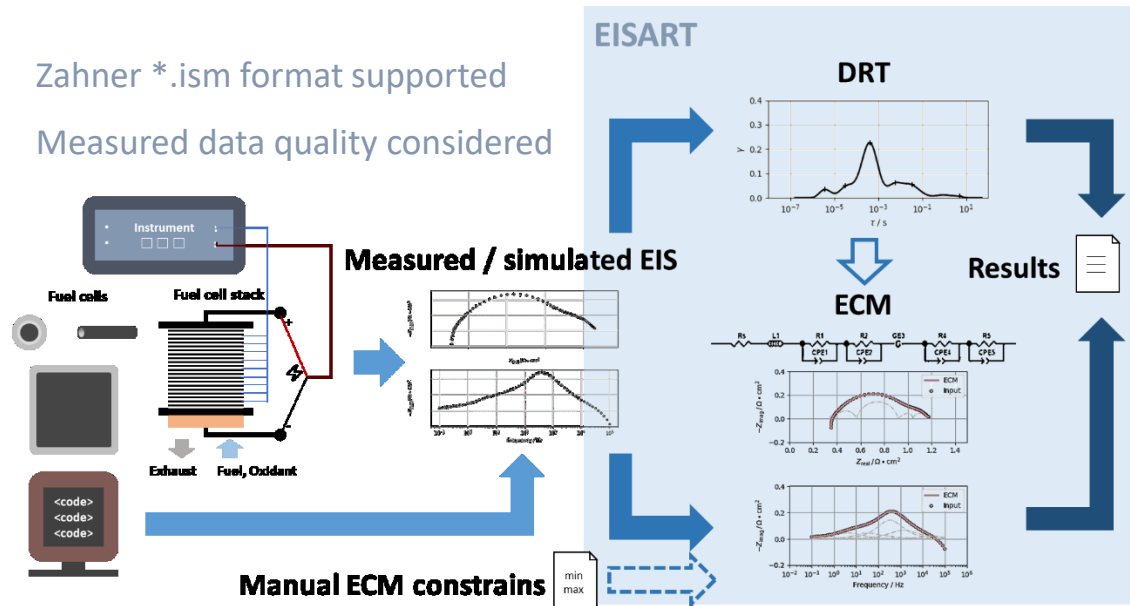




# 1 Introduction

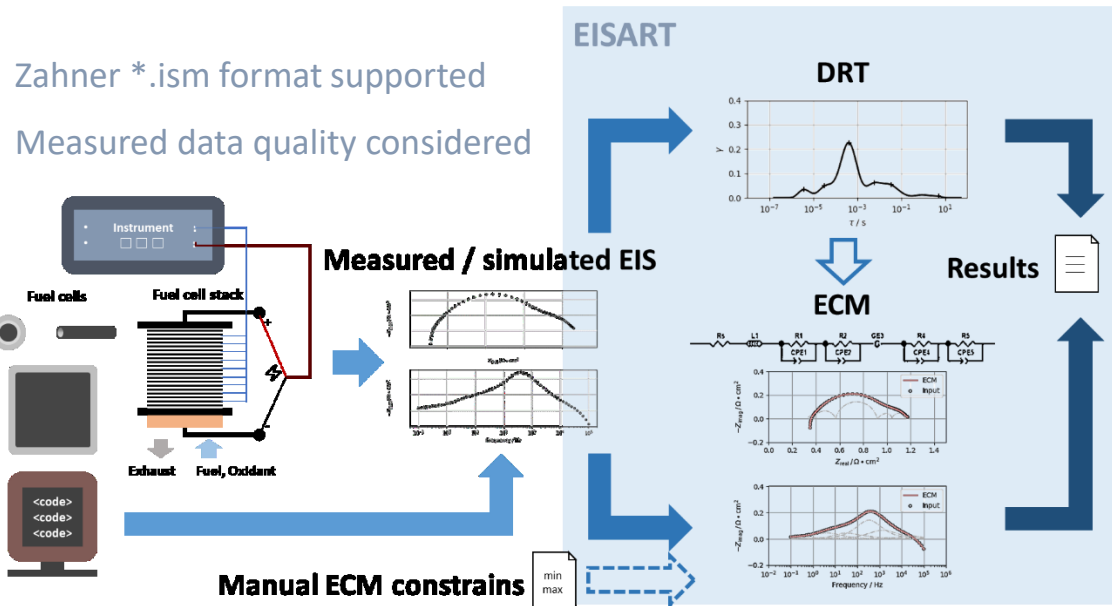
## 1.1 Functionality

EISART offers the possibility to **save the desired part** of results as **files** in the specified format. It currently supports \*.txt and \*.csv. The files are saved in the same directory as the input EIS data file. The snapshot for the input file can also be automatically saved.



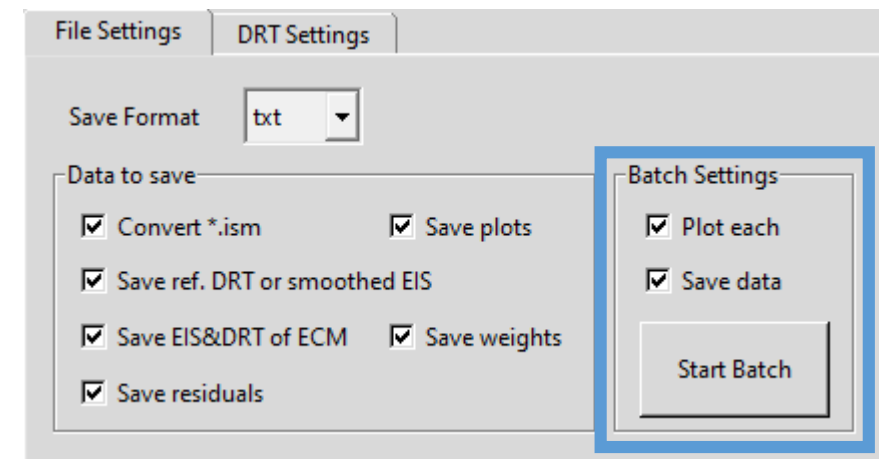
# 1 Introduction

## 1.1 Functionality



**Batch processing** using the same settings is possible with one click.

Results can be plotted in real time during batch processing. The snapshot for each input file can also be automatically saved during batch processing.



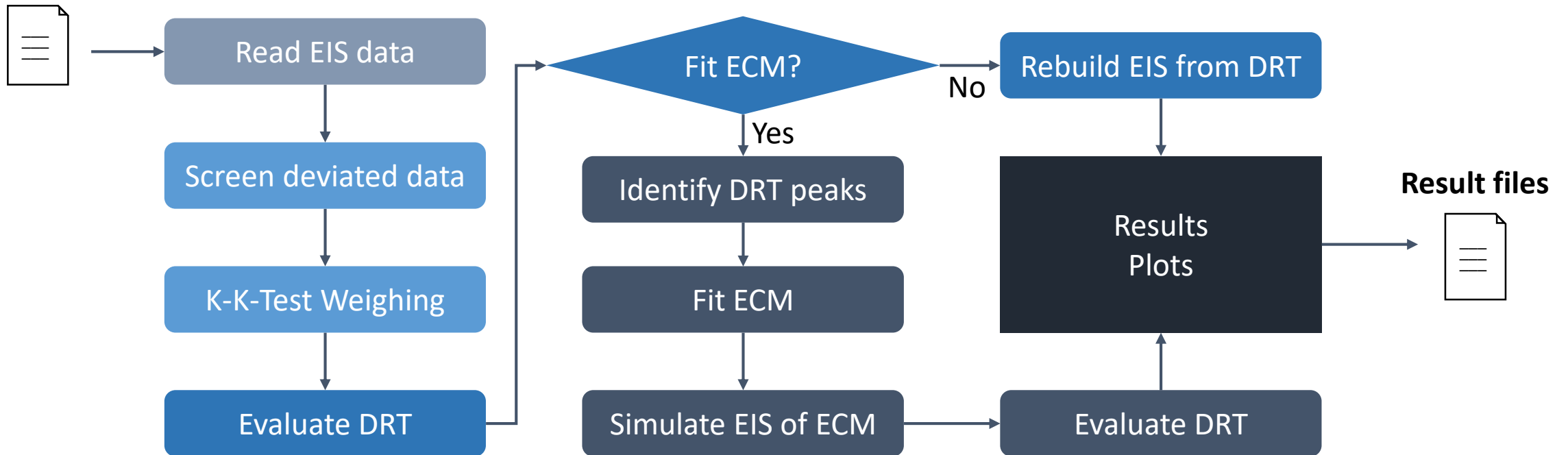
# 1 Introduction

## 1.2 Basic workflow

EISART process an input file in multiple steps as are shown below. The Graphical User Interface (GUI) of EISART will guide its users through these steps.

Whether or not to fit an ECM results in two different workflows.

**EIS data file**



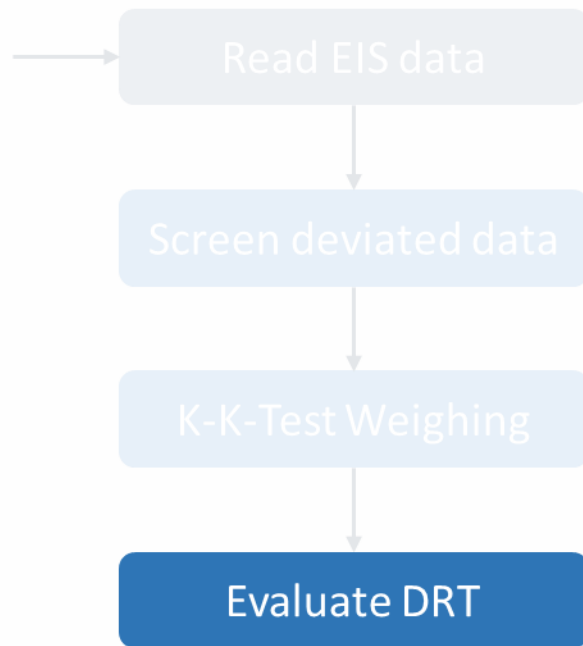
# 1 Introduction

## 1.2 Basic workflow

The DRT result in EISART contains the **relaxation time distribution function**  $\gamma(\tau)$  and its corresponding **relaxation time**  $\tau$  (tau). The DRT is related to the input EIS with the following equation:

$$Z(\omega) = \int_0^{+\infty} \frac{\gamma(\tau)d\tau/\tau}{1 + 1j \cdot \omega\tau} = \int_{-\infty}^{+\infty} \frac{\gamma(\tau)d\ln(\tau)}{1 + 1j \cdot \omega\tau}$$

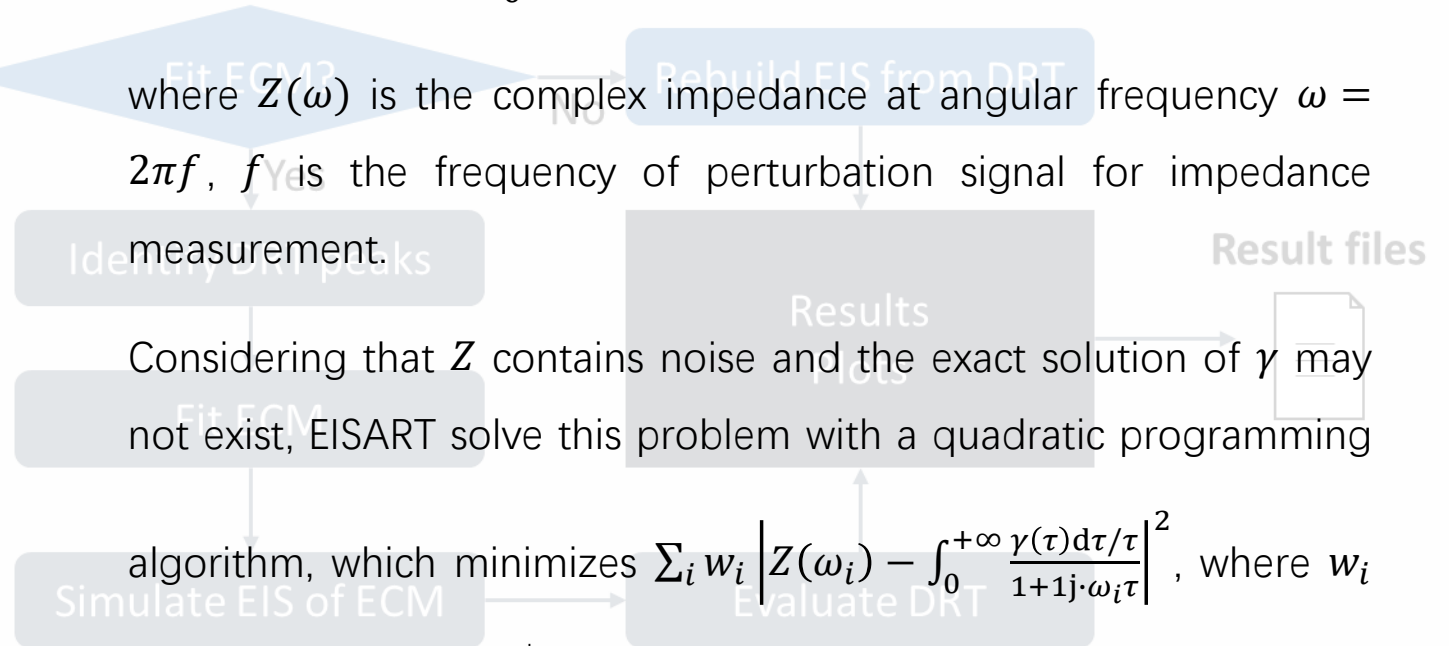
EIS data file



where  $Z(\omega)$  is the complex impedance at angular frequency  $\omega = 2\pi f$ ,  $f$  is the frequency of perturbation signal for impedance measurement.

Considering that  $Z$  contains noise and the exact solution of  $\gamma$  may not exist, EISART solve this problem with a quadratic programming

algorithm, which minimizes  $\sum_i w_i \left| Z(\omega_i) - \int_0^{+\infty} \frac{\gamma(\tau)d\tau/\tau}{1+1j \cdot \omega_i\tau} \right|^2$ , where  $w_i$  is the weight on the  $i^{\text{th}}$  frequency point.



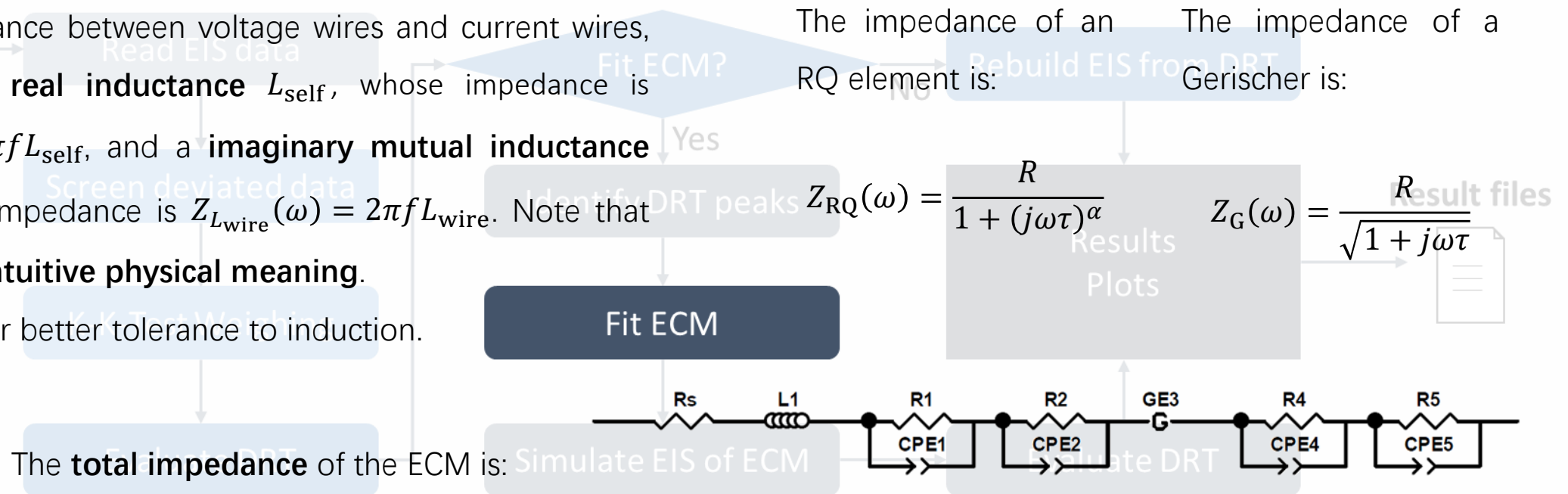
# 1 Introduction

## 1.2 Basic workflow

The ECM in EISART may contain series connected **resistor**  $R_s$ , **inductor**, **RQ elements** (or ZARC elements, a resistor in parallel with a constant phase element or CPE), and **Gerischers** (G elements).

To involve the effect of both self inductance of the wiring and mutual inductance between voltage wires and current wires, EISART fits a **real inductance**  $L_{\text{self}}$ , whose impedance is  $Z_{L_{\text{self}}}(\omega) = 2j\pi f L_{\text{self}}$ , and a **imaginary mutual inductance**  $L_{\text{wire}}$ , whose impedance is  $Z_{L_{\text{wire}}}(\omega) = 2\pi f L_{\text{wire}}$ . Note that  $L_{\text{wire}}$  has **no intuitive physical meaning**. It only exists for better tolerance to induction.

The impedance of an RQ element is:  $Z_{\text{RQ}}(\omega) = \frac{R}{1 + (j\omega\tau)^\alpha}$   
 The impedance of a Gerischer is:  $Z_G(\omega) = \frac{R}{\sqrt{1 + j\omega\tau}}$



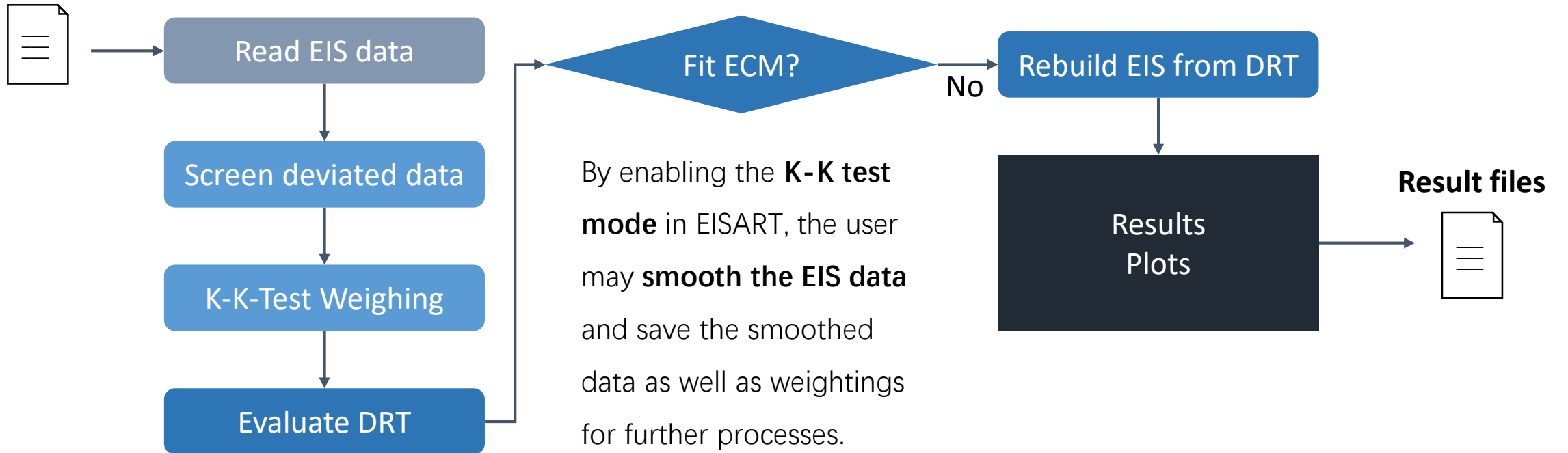
$$Z_{\text{total}}(\omega) = R_s + Z_{L_{\text{self}}}(\omega) + Z_{L_{\text{wire}}}(\omega) + \sum Z_{\text{RQ}}(\omega) + \sum Z_G(\omega)$$

# 1 Introduction

## 1.2 Basic workflow

If not to fit an ECM, EISART works as a **data inspector** and runs significantly faster (typically  $< 1$  s). The user may check EIS data quality and the reliability of DRT analysis results.

EIS data file

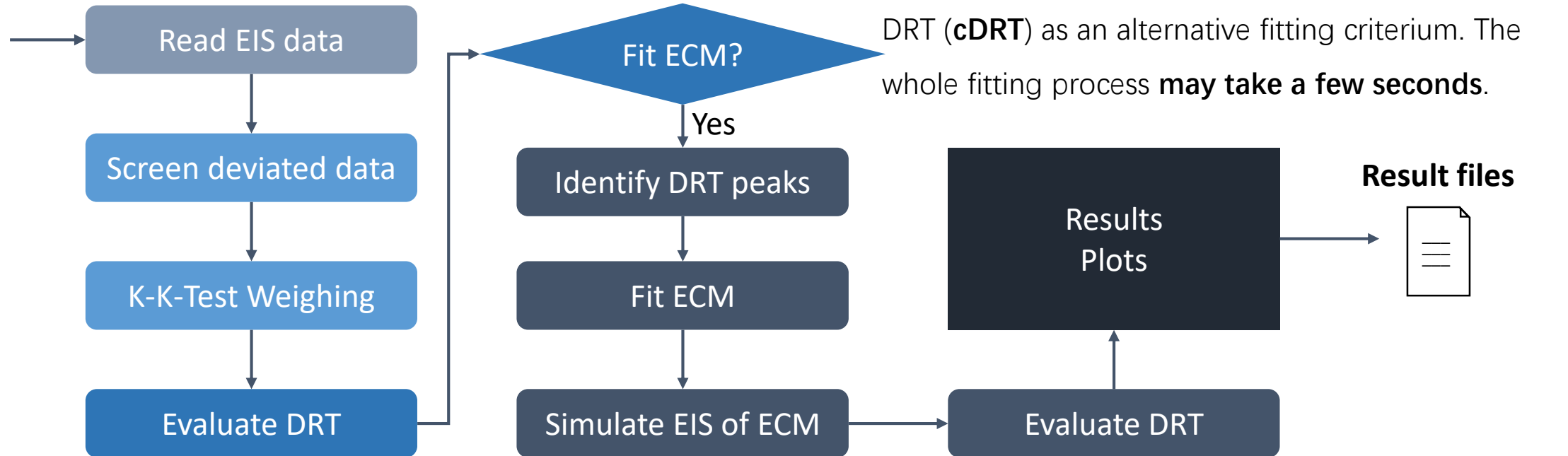


# 1 Introduction

## 1.2 Basic workflow

If to fit an ECM, EISART can **automatically identify DRT peaks** as indicators of ECM parameters. The user may also **manually specify constraints to ECM parameters**. EISART fit an ECM with the Complex Nonlinear Least Squares (**CNLS**) algorithm.

EIS data file



Besides the input EIS data, EISART offers cumulative DRT (**cDRT**) as an alternative fitting criterium. The whole fitting process **may take a few seconds**.

# 1 Introduction

## 1.3 Using the GUI

### File browsing panel

Select an EIS data file

You may click the “Browse” button to choose a file, or enter/paste a path to the file, and then press “Enter” on your keyboard.

You may try the EIS files in the “**samples**” folder that is in the EISART package.

### Active cell area

Enter active cell area in  $\text{cm}^2$  so that EISART gives the right results in  $\Omega \cdot \text{cm}^2$

You may **double-click** a file in File browsing panel or **press Enter** in the Active cell area entry box to refresh **the plot**.

### Plot region

The input and output data is visualized in the plot region with a Nyquist plot, a Bode plot, a DRT plot, and a residual plot.

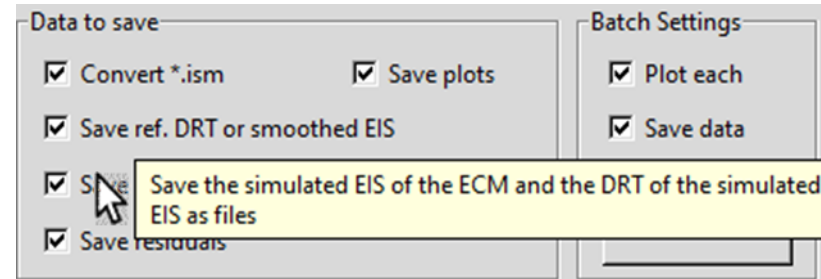


You may use the plot controller buttons to pan, zoom or save the plot.



# 1 Introduction

## 1.3 Using the GUI

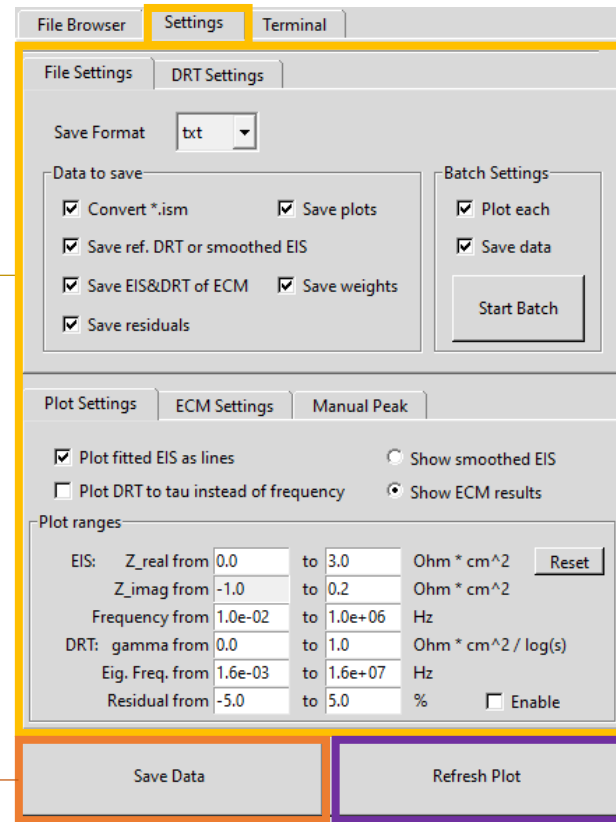


### Hints

Place the mouse over text widgets and the hints will show.

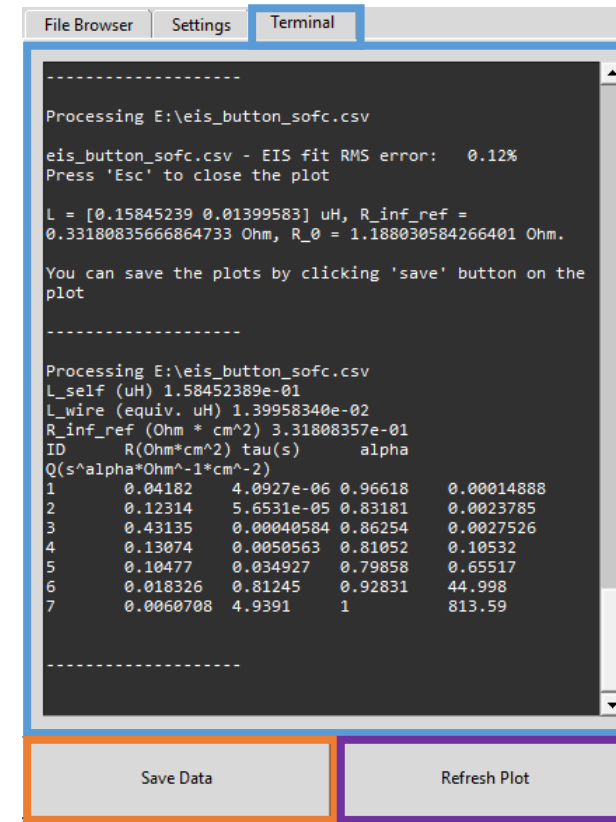
### Settings

Control options for the data processing workflow, parameters etc.



### Save Data

Re-calculate, plot, and save the results.



### Terminal

The text output portal of EISART, shows the results in text.

### Refresh Plot

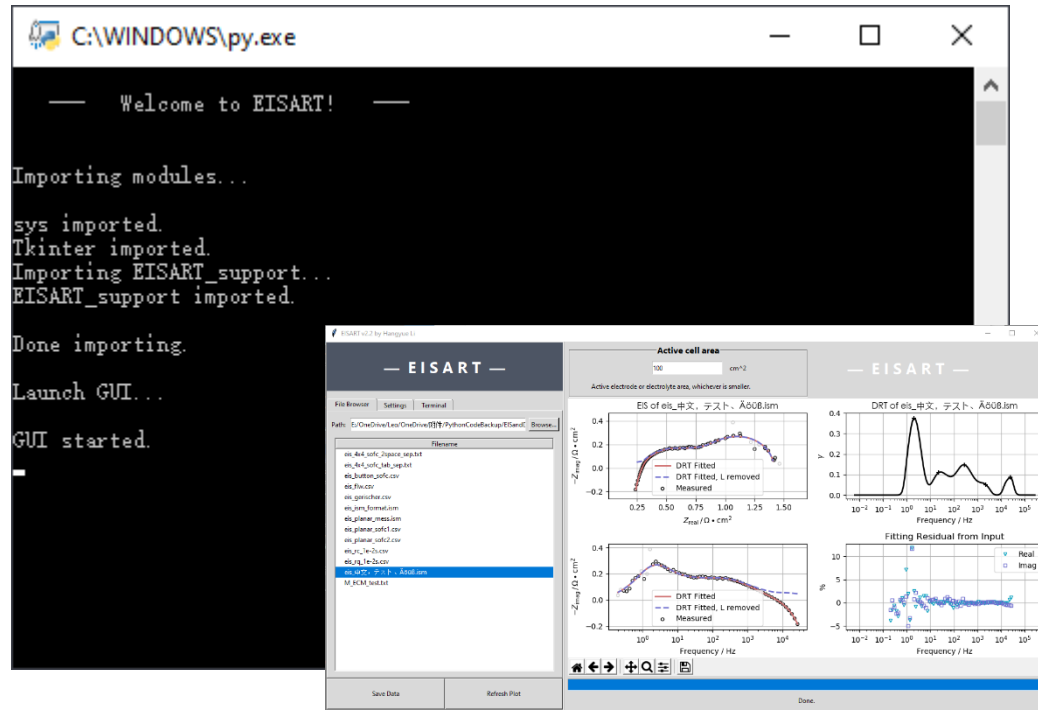
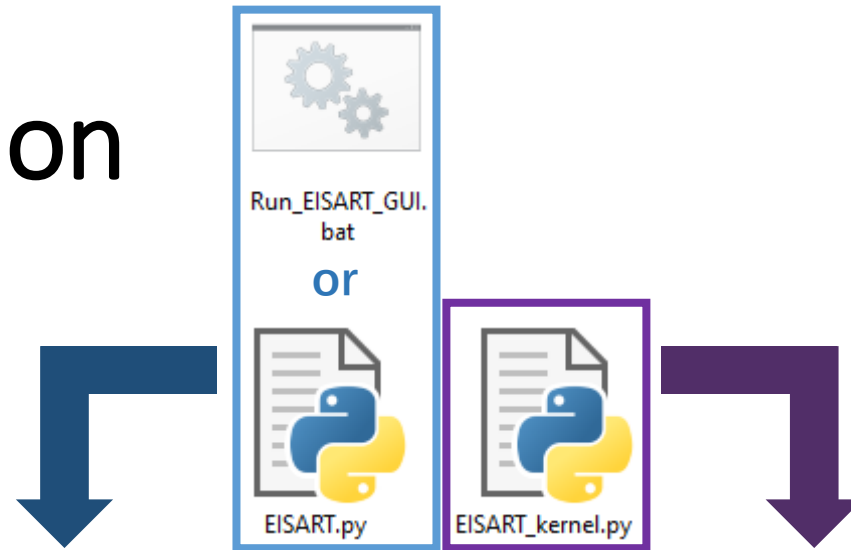
Re-calculate, plot, but not save the results.

# 1 Introduction

## 1.3 Using the GUI

Besides the GUI, EISART has a Text User Interface (TUI) when the GUI is running. It may show valuable information for debugging.

The kernel of EISART can be launched without GUI.



```
>>> >>> >>> >>> EISART <<< <<< <<< <<<
Electrochemical Impedance Spectra Analysis & Refining Tool
code by Hangyue Li, THU

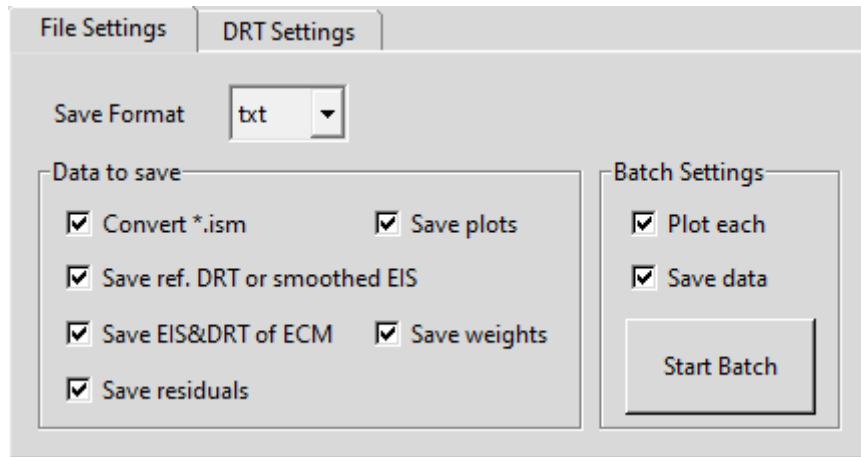
Please drop an EIS data file or folder here.
>>>
```

# 2 Settings

## 2.1 File and DRT Settings

File Settings:

controls visual and file output



The screenshot shows a software window titled 'File Settings' with a tab labeled 'DRT Settings'. Inside the window, there is a 'Save Format' dropdown menu currently set to 'txt'. Below this, there are two main sections: 'Data to save' and 'Batch Settings'. The 'Data to save' section contains five checkboxes, all of which are checked: 'Convert \*.ism', 'Save ref. DRT or smoothed EIS', 'Save EIS&DRT of ECM', 'Save residuals', 'Save plots', and 'Save weights'. The 'Batch Settings' section contains two checkboxes, both checked: 'Plot each' and 'Save data'. At the bottom right of the 'Batch Settings' section is a button labeled 'Start Batch'.

**Save Format:** controls extension of the saved files, **txt** (tab separated) or **csv** (comma separated).

**Data to save:** controls which part of the result to save, if applicable.

[For more information, please see Output.](#)

**Batch Settings:** controls visual and data output when running a batch.

# 2 Settings

## 2.1 File and DRT Settings

DRT Settings: controls how DRT is evaluated. This also affects ECM fitting

The screenshot shows the 'DRT Settings' dialog box. It has two tabs: 'File Settings' and 'DRT Settings'. The 'DRT Settings' tab is selected. Inside, there are several sections: 'K-K Test Mode' with an unchecked checkbox, 'False Peak Sup.' with a checked checkbox, and 'Weight Iter.' with a spinner set to 0. Below these are 'Regularization' and 'Screening' sections. 'Regularization' has 'Auto lambda' unchecked, 'Lambda' set to 0.001, and 'Radius' set to 1.0. 'Screening' has 'Unskip' set to 5, 'Filter lvl.' set to 0.8, and 'Max Trim' set to 10. On the right is a 'Ranges' section with four spinners, all set to 0.0: 'EIS LF. Dis. Dec.', 'EIS HF. Dis. Dec.', 'DRT LF. Ext. Dec.', and 'DRT HF. Ext. Dec.'.

**K-K Test Mode:** display K-K test results. Only applicable when ECM is not fitted (otherwise K-K tests would be done but not shown). The unweighted algorithm is proposed by Schönleber et al.

**False Peak Sup.:** suppress possibly false peaks in DRT at the very edge of the range of relaxation time.

**Weight Iter.:** re-weighting iteration count. Weights are updated according to the error in weighted K-K tests.

**Regularization:** control options for Tikhonov regularization in DRT evaluation.

**Screening:** control options for EIS data screening (downweighting “bad” data points).

**Ranges:** ranges for evaluated frequencies in EIS data and relaxation time in DRT.

# 2 Settings

## 2.1 File and DRT Settings

DRT Settings: controls how DRT is evaluated. This also affects ECM fitting

The screenshot shows the 'DRT Settings' dialog box. It has two tabs: 'File Settings' and 'DRT Settings'. The 'DRT Settings' tab is active. The 'K-K Test Mode' checkbox is unchecked, and the 'False Peak Sup.' checkbox is checked. The 'Weight Iter.' is set to 0. The 'R\_inf =' entry box is highlighted with a blue border. The 'L =' entry box is also visible. The 'Regularization' section has 'Auto lambda' unchecked, 'Lambda' set to 0.001, and 'Radius' set to 1.0. The 'Screening' section has 'Unskip' set to 5, 'Filter lvl.' set to 0.8, and 'Max Trim' set to 10. The 'Ranges' section has four entries, all set to 0.0: 'EIS LF. Dis. Dec.', 'EIS HF. Dis. Dec.', 'DRT LF. Ext. Dec.', and 'DRT HF. Ext. Dec.'.

**R<sub>inf</sub>** = : user-specified R<sub>inf</sub> or ohmic resistance in  $\Omega \cdot \text{cm}^2$ . The value you specified in this entry box will remain unchanged throughout the analysis. Leave this entry box blank if you want EISART to find R<sub>inf</sub> for you.

**L** = : user-specified inductance in equivalent  $\mu\text{H}$ . The value you specified in these two entry boxes will remain unchanged throughout the analysis. The entry box on the left stands for the self inductance of the test object and affects only the imaginary part of impedance. The entry box on the right stands for the estimated mutual induction effect between current cables and voltage wires, and affects only the real part of impedance. Leave any of or both the entry boxes if you want EISART to find L for you.

# 2 Settings

## 2.1 File and DRT Settings

DRT Settings: controls how DRT is evaluated. This also affects ECM fitting

The screenshot shows the 'DRT Settings' dialog box. The 'Regularization' section is highlighted with a blue box. It contains the following settings:

- ☐ K-K Test Mode
- ☒ False Peak Sup.
- Weight Iter. 0
- R\_inf =
- L = ,
- Regularization**
  - ☐ Auto lambda
  - Lambda 0.001
  - Radius 1.0
- Screening**
  - Unskip 5
  - Filter lvl. 0.8
  - Max Trim 10
- Ranges**
  - EIS LF. Dis. Dec. 0.0
  - EIS HF. Dis. Dec. 0.0
  - DRT LF. Ext. Dec. 0.0
  - DRT HF. Ext. Dec. 0.0

**Regularization:** control options for Tikhonov regularization in DRT evaluation. Lambda ( $\lambda$ ) is the **regularization parameter** for all frequencies in the input EIS.

If **Auto lambda** is enabled, lambda may increase for frequencies in the input EIS data with lower weights. This option may **reduce the resolution** of DRT, but increase the **robustness** of DRT result **to disturbances** in the input EIS data.

If auto lambda is NOT enabled, the recommended value for **lambda** is 0.001, for a balance of DRT resolution and variance for input EIS noise level of  $\pm 0.5\%$ . If the **noise level is higher**, larger lambda is recommended.

# 2 Settings

## 2.1 File and DRT Settings

DRT Settings: controls how DRT is evaluated. This also affects ECM fitting

The screenshot shows the 'DRT Settings' dialog box. The 'Screening' section is highlighted with a blue box. It contains three settings: 'Unskip' set to 5, 'Filter lvl.' set to 0.8, and 'Max Trim' set to 10. Other settings include 'K-K Test Mode' (unchecked), 'False Peak Sup.' (checked), 'Weight Iter.' set to 0, 'Regularization' (unchecked), 'Auto lambda' (unchecked), 'Lambda' set to 0.001, 'Radius' set to 1.0, and a 'Ranges' section with four settings all set to 0.0.

**Screening:** control options for EIS data screening (downweighing “bad” data points).

The input EIS data is examined **point-wise** by the screener. The screener checks for the “worst” data point, downweigh it if it meets the screening rules, and then move to the next point. The screener terminate screening if the next data point is “good enough”.

**Unskip** defines the minimum number of points to be examined by the screener. This may cause the screener to ignore terminating signals and examining more points, but not necessarily trim more.

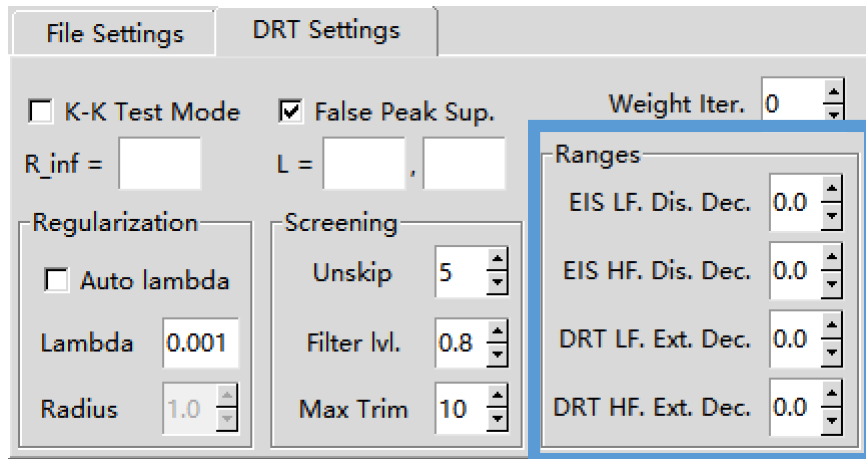
Filter level (**Filter lvl.**) defines the screening rules that tells the screener whether to move to the next data point or terminate. The higher this value, the more likely data points are treated as bad points.

**Max Trim** defines the maximum number of EIS data points to be trimmed by the data quality filter. This may override Unskip.

# 2 Settings

## 2.1 File and DRT Settings

DRT Settings: controls how DRT is evaluated. This also affects ECM fitting



The screenshot shows the 'DRT Settings' dialog box. The 'DRT Settings' tab is selected. The 'Ranges' section is highlighted with a blue box. It contains four settings: 'EIS LF. Dis. Dec.' (0.0), 'EIS HF. Dis. Dec.' (0.0), 'DRT LF. Ext. Dec.' (0.0), and 'DRT HF. Ext. Dec.' (0.0). Other settings include 'K-K Test Mode' (unchecked), 'False Peak Sup.' (checked), 'Weight Iter.' (0), 'Regularization' (Auto lambda unchecked, Lambda 0.001, Radius 1.0), and 'Screening' (Unskip 5, Filter lvl. 0.8, Max Trim 10).

**Ranges:** ranges for evaluated frequencies in EIS data and relaxation time in DRT.

**EIS LF. Dis. Dec.:** number of decades to be discarded in the low-frequency end of the input EIS data. Use this when the low-frequency end of EIS data is of poor quality.

**EIS HF. Dis. Dec.:** number of decades to be discarded in the high-frequency end of the input EIS data. Use this when the high-frequency end of EIS data is of poor quality.

**DRT LF. Ext. Dec.:** number of decades of the lowest frequencies / longest taus in DRT extended beyond the analyzed EIS frequency range. Recommended values are below 1.0

**DRT HF. Ext. Dec.:** number of decades of the highest frequencies / shortest taus in DRT extended beyond the analyzed EIS frequency range. Recommended values are below 1.0



# 2 Settings

## 2.2 Plot and ECM Settings

Plot Settings:

Controls the workflow and plot options

Plot Settings

ECM Settings

Manual Peak

☒ Plot fitted EIS as lines

☐ Show smoothed EIS

☐ Plot DRT to tau instead of frequency

☒ Show ECM results

Plot ranges

EIS: Z\_real from 0.0 to 3.0 Ohm \* cm^2

Z\_imag from -1.0 to 0.2 Ohm \* cm^2

Frequency from 1.0e-02 to 1.0e+06 Hz

DRT: gamma from 0.0 to 1.0 Ohm \* cm^2 / log(s)

Eig. Freq. from 1.6e-03 to 1.6e+07 Hz

Residual from -5.0 to 5.0 %

Reset

Enable

**Plot ranges** controls the range to show in the plots. If not enabled, the ranges are automatically determined.

Plot settings

Plot fitted EIS as lines:

(Fig. 1)

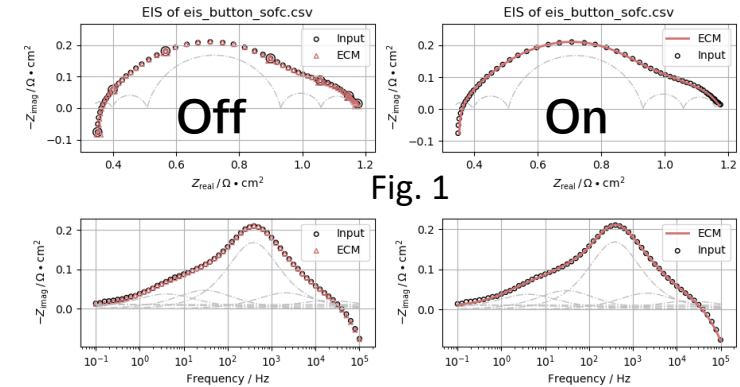


Fig. 1

Plot DRT to tau instead of frequency: this also updates the GUI

(Fig. 2)

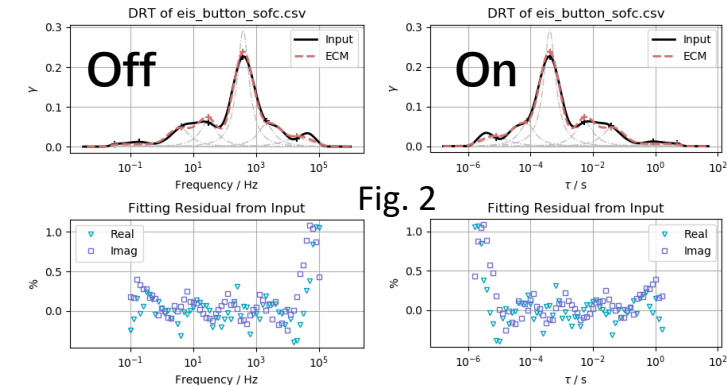


Fig. 2

Show smoothed EIS:

(Fig. 3)

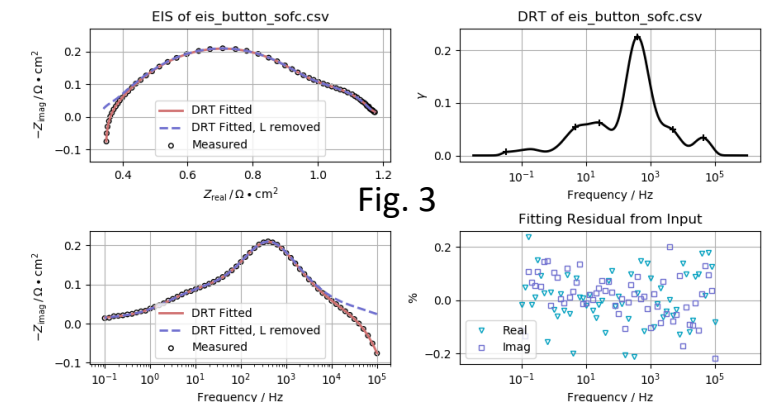


Fig. 3

Show ECM results

(as is shown in Fig. 1 and Fig. 2)

# 2 Settings

## 2.2 Plot and ECM Settings

ECM Settings:

Controls ECM fitting process

Plot Settings | **ECM Settings** | Manual Peak

DRT peak detection

☒ Auto    Peak Damping: 0.1    Max Num. Peak: 7

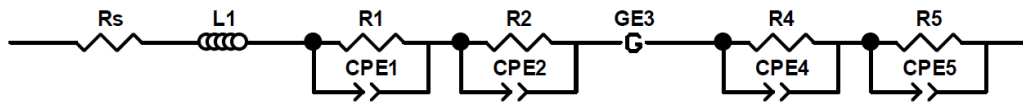
Base on: ☒ EIS    Gerischer Positions:

CNLS based on EIS

☒ Fit tau  
☒ Iterate alpha  
☐ Fit element-wise

CNLS based on CDRT

☐ Coupled R-tau-alpha    ☒ Fit R  
☒ Fit from default pars.    ☒ Fit tau  
   ☒ Fit alpha



**ECM Settings:** settings for fitting an ECM, only usable when “Show ECM results” in Plot Settings is selected.

**DRT peak detection:** how the peaks in DRT are detected for ECM.

Auto: automatically detect the peaks.

Peak Damping: how sensitive the detector to peaks is.

Max Num. Peak: the maximum number of peaks to be detected.

**Based on:** whether to minimize the fitting results according to EIS or cumulative DRT (cDRT or CDRT). Fitting to CDRT is only recommended if all peaks are blurred (short and wide).

**Gerischer Positions:** the positions of RQ elements to be replaced with Gerischers.

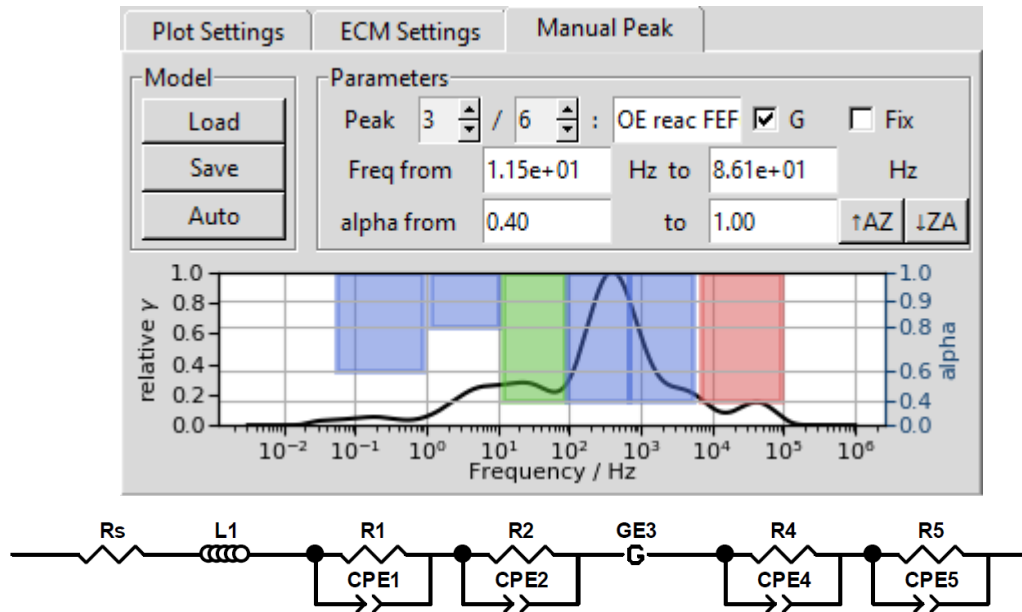
**CNLS based on EIS / CDRT:** options for complex nonlinear least squares (CNLS) fitting. Please see the hints in the GUI.

# 2 Settings

## 2.2 Plot and ECM Settings

Manual Peak:

Controls manual peak / ECM constrains.



**Manual Peak:** manual peak / ECM constrain settings. This tab is only usable when **Auto** peak detection in ECM Settings is **NOT** enabled.

You may **load** ECM constrains from a file or **save** them as a file. ZView \*.mdl model can be loaded here if its circuit model is compatible with EISART.

You may also let EISART **automatically** generate ECM constrains as a starting point for you.

You may **select** the peak (ECM element) you wish to view or modify, or **add** / **remove** / **sort** elements as you wish.

The constrains on peak parameters are plotted as **rectangles** on the tab in real time as you edit them.

The fitting does not adjust tau and alpha of a peak if it is **fixed** (in red), while its R may still be adjusted.

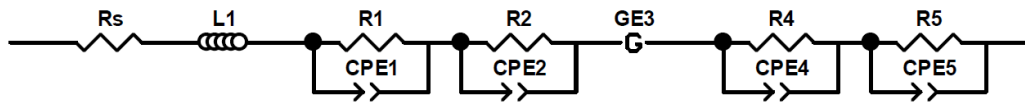
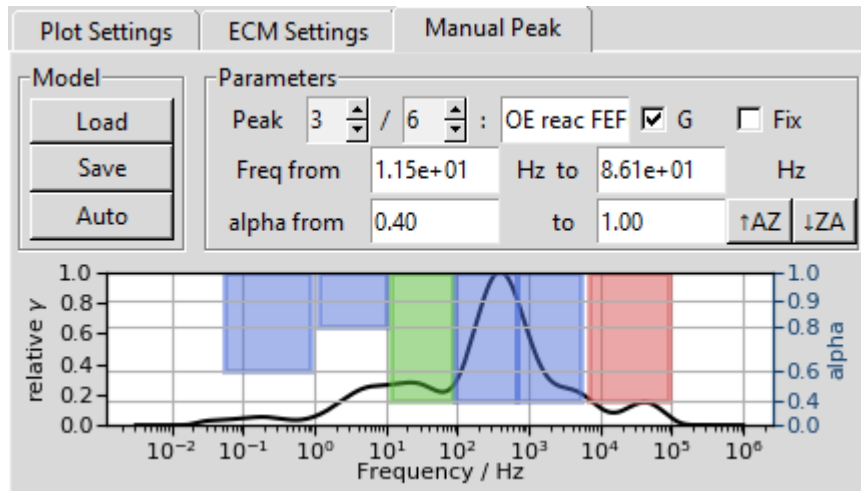
Unfixed Gerischers are plotted green, RQ elements are plotted blue.

# 2 Settings

## 2.2 Plot and ECM Settings

Manual Peak:

Controls manual peak / ECM constrains.



About the elements in ECM:

An RQ element has 3 parameters: R, tau ( $\tau$ ) and alpha ( $\alpha$ )

A Gerischer has 2 parameters: R and tau ( $\tau$ )

For mathematical definitions, see [workflow](#).

R is the DC resistance of an RQ element or a Gerischer. A larger R corresponds to a larger arc in Nyquist plot and larger area below a peak in DRT.

tau is the time constant of an RQ element or a Gerischer. Varying tau corresponds to a horizontally translating peak in DRT.

alpha is the dispersion exponent of an RQ element. It ranges from 0 to 1. A smaller alpha corresponds to a flatter arc in Nyquist plot and a flatter, wider peak in DRT.

# 3 Input/Output File Format

## 3.1 Input file format

For \*.txt and \*.csv format:

Input EIS data file should contain 3 columns with or without title:

Frequency, the real and the imaginary part of impedance.

For \*.txt format, columns can be separated by arbitrary many **tabs** or **white spaces**.

For \*.csv format, columns are separated by **commas**.

Decimal points should be **dots**.

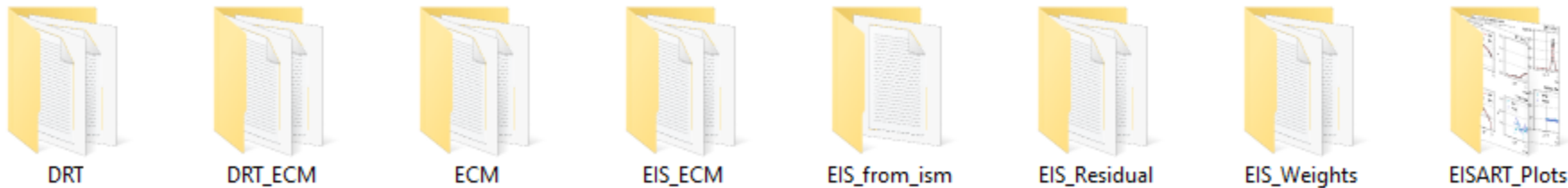
If the unit of impedance is  $\Omega \cdot \text{cm}^2$ , the active cell area in EISART should be  $1.0 \text{ cm}^2$ .

\*.ism formatted binary files saved by Thales software using Zahner instruments can be directly loaded into EISART.

$f$ (Hz)	real( $Z$ )	imag( $Z$ ) ( $\Omega$ )
54463	0.011942	0.002333
44954	0.012158	0.0016927
37105	0.012288	0.0010789
30627	0.012461	0.00057649
25279	0.012694	0.00012743
20866	0.012906	-0.0002106
17223	0.013127	-0.0005367
14216	0.013385	-0.00078684
11734	0.0137	-0.00094189
9685	0.013932	-0.0010762
7994	0.014161	-0.0011479
6598	0.014415	-0.0011877

# 3 Input/Output File Format

## 3.2 Output: folders created by EISART



**DRT:** DRT results of the input EIS data

**DRT\_ECM:** DRT results of EIS\_ECM

**ECM:** the parameters of each element in ECM

**EIS\_ECM:** the simulated EIS of ECM

**EIS\_from\_ism:** original EIS data from \*.ism files

**EIS\_Residual:** relative residual to the input data

**EIS\_Weights:** weights applied on the EIS data

**EISART\_Plots:** plots/snapshots from EISART

Data is marked with text

Data is marked with text

Data is marked with text, parameter Q included, G stands for Gerischer and \*.mdl models for ZView

Frequency, the real and the imaginary part of impedance

Frequency, the real and the imaginary part of impedance

Frequency, relative residuals of the real and the imaginary part of impedance

Frequency, weights on the real and the imaginary part of impedance

As the plot displayed in the plot region in GUI, \*.png format

Default units are: Hz for frequency, second for tau,  $\Omega \cdot \text{cm}^2$  for impedance,  $\Omega \cdot \text{cm}^2 / \ln(\text{second})$  for  $\gamma$  in DRT.

# 4 About



固体氧化物燃料电池实验室  
Solid Oxide Fuel Cell Laboratory

**EISART** is developed by Hangyue Li in the research group of Prof. Minfang Han in the Department of Energy and Power Engineering, Tsinghua University, Beijing, China.

<https://scholar.google.com/citations?user=p0S-PukAAAAJ&hl=zh-CN>

<http://www.depe.tsinghua.edu.cn/depeen/info/1035/1131.htm>

[https://www.researchgate.net/profile/Hangyue\\_Li](https://www.researchgate.net/profile/Hangyue_Li)

# 5 References

- EIS and ECM Fundamentals:

<https://orbit.dtu.dk/files/2369271/Electrochemical%20characterisation%20and%20performance%20evaluation.pdf>

- K-K Test: M. Schönleber et al. (2014), Electrochimica Acta vol.131, pages20-27

- DRT: <https://ciucci.org/project/drt/>

DRTtools: T. Wan et al. (2015), Electrochimica Acta, vol.184, pages483-499

Hyper  $\lambda$ : Effat et al. (2017), Electrochimica Acta, vol.247, pages1117-1129

- ECM:

RQ element (<http://www.consultrsr.net/resources/eis/zarc.htm>) Gerischer (<http://www.consultrsr.net/resources/eis/gerischer.htm>)