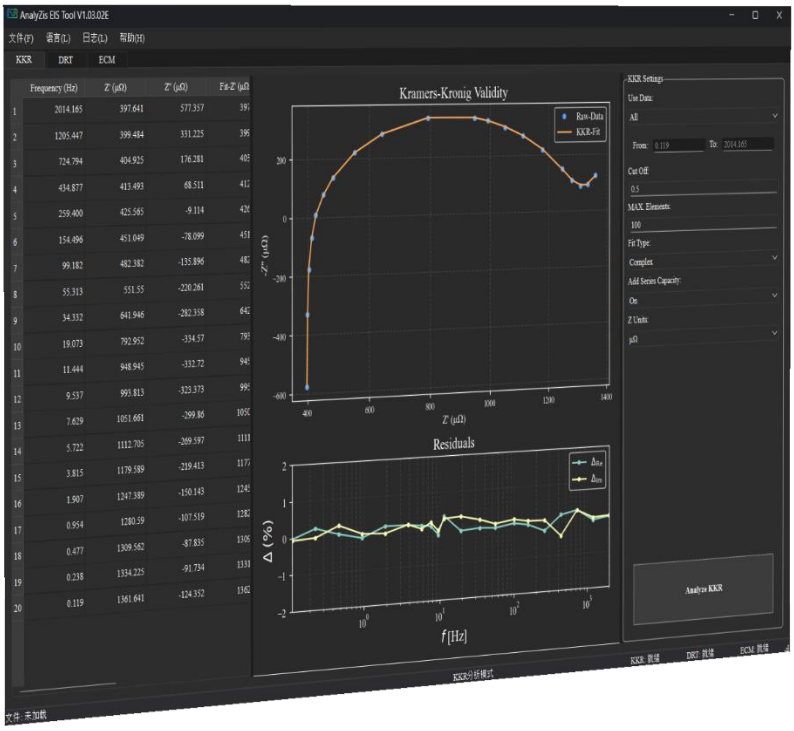
AnalyZis

EIS Analysis Software

User Manual



2025.10.12 v1.01

Contents

1. Software Overview....3
   1.1. Software Introduction....3
   1.2. Main Functional Features....3
   1.3. System Requirements....4
   1.4. Installation and Startup....4
2. Quick Start....5
   2.1. Interface Layout Introduction....5
   2.2. Basic Operational Procedures....6
   2.3. Shortcut Key Descriptions....7
3. Data Import....9
   3.1. Supported File Formats....9
   3.2. Data Format Requirements....9
   3.3. Detailed Import Steps....10
   3.4. Common Import Issues and Solutions....11
4. KKR Verification Function....13
   4.1. Introduction to Kramers-Kronig Relation (KKR)....13
   4.2. Parameter Setting Details....14
   4.3. Analysis Result Interpretation....15
   4.4. Application Cases....16
5. DRT Analysis Function....18
   5.1. Introduction to the Principle of Relaxation Time Distribution....18
   5.2. Detailed Explanation of Parameter Settings....19
   5.3. Application cases....21
6. ECM Fitting Function....22
   6.1. Introduction to the Principles of Equivalent Circuit Models....22
   6.2. Parameter Fitting and Optimization....24
   6.3. Interpretation of Analysis Results....24
   6.4. Application cases....27
7. Data Visualization....29
   7.1. Nyquist Curve Operation Guide....29
   7.2. Bode Plot Operation Guide....30
8. Data and Chart Export....32
   8.1. Analysis Data Export....32
   8.2. Chart Export....32
9. Advanced Features....34
   9.1. Unit System Settings....34
   9.2. Multilingual Support....34
   9.3. Log Management....35
10. Contact....36
Copyright Information....37

1. Software Overview

1.1. Software Introduction

AnalyZis is a professional Electrochemical Impedance Spectroscopy (EIS) analysis software developed by Shanghai Zhiyuan Suanneng New Energy Technology Co., Ltd. The software integrates three core functional modules: Kramers-Kronig Relation (KKR) verification, Distribution of Relaxation Times (DRT) analysis, and Equivalent Circuit Modeling (ECM), providing electrochemical researchers with a comprehensive data analysis solution.

Employing advanced algorithms and a user-friendly graphical user interface, AnalyZis supports the import of multiple data formats and offers rich visualization tools and detailed statistical reports. It aims to assist users in gaining a deeper understanding of the kinetic processes and interfacial characteristics of electrochemical systems.

1.2. Main Functional Features

✧ Core Analysis Modules

1) **KKR Analysis:** Verifies the causality, linearity, and stability of EIS data based on the Kramers-Kronig relation.
2) **DRT Analysis:** Reveals the kinetic processes of electrochemical systems through distribution of relaxation times analysis.
3) **ECM Analysis:** Provides equivalent circuit model fitting and parameter optimization functions.

✧ Data Processing Features

1) Supports the import of various data formats including CSV, TXT, and Excel.
2) Automatically detects file encoding and delimiters.
3) Offers data range screening and filtering capabilities.
4) Provides real-time data preview and validation.

✧ Visualization Features

1) Displays high-quality Nyquist and Bode plots.
2) Enables interactive chart operations (zooming, panning, resetting).
3) Manages multi-subplot layouts.
4) Customizes chart styles and themes.

✧ Output and Export Features

1) Generates detailed data analysis reports.
2) Exports charts in multiple formats (PNG, SVG, JPEG).
3) Offers data table export functionality.

4) Provides complete ECM parameter statistical information.

✧ User Interface Characteristics

1) Multilingual support (Chinese, English).
2) Light/dark theme switching.
3) Intelligent tooltips and help systems.
4) Intuitive parameter setting interface.

1.3. System Requirements

✧ Minimum Configuration Requirements

1) Operating System: Windows 10 or higher.
2) Processor: Intel Core i5 or equivalent AMD processor.
3) Memory: 8 GB RAM.
4) Hard Disk Space: 2 GB available space.
5) Display: 1024×768 resolution

✧ Recommended Configuration

1) Operating System: Windows 11.
2) Processor: Intel Core i7 or higher performance processor.
3) Memory: 16 GB RAM or higher.
4) Hard Disk Space: 5 GB available space (SSD recommended).
5) Display: 1920×1080 or higher resolution.
6) Graphics Card: Dedicated graphics card (for accelerated graphics rendering)

1.4. Installation and Startup

✧ Installation Steps

1) Download the ZIP compressed package from the official website.
2) Extract the package to the specified directory for installation-free operation.

✧ Startup Method

1) Double-click the AnalyZis_EIS_Tool_vX.XX.XXE.exe executable file in the software directory to launch the "AnalyZis" software.
2) If permission issues arise, right-click the executable file and select "Run as administrator."

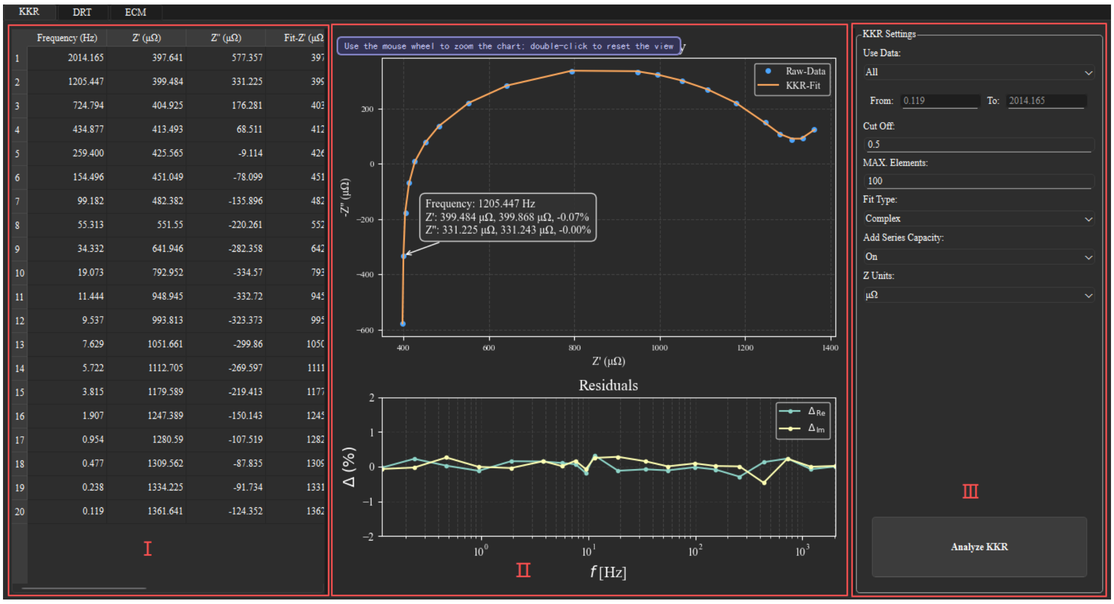
Note: New users are advised to read the operational guidelines in subsequent chapters to fully utilize the software's features. For installation or startup issues, contact technical support.

2. Quick Start

2.1. Interface Layout Introduction

AnalyZis employs an intuitive, adjustable three-partition interface design to provide users with an efficient workflow.

✧ Main Interface Structure



I. **Left Panel:**
- Data table display area.
- Raw data and fitting results tables.
- Real-time data display and filtering functions.
- Data statistical information display.

II. **Central Panel：**
- Chart visualization area.
- Interactive chart operation controls.
- Circuit diagram and statistical information display area (ECM page).

III. **Right Panel:**
- Parameter setting area.
- Analysis parameter configuration.
- Algorithm option settings.
- Execution control buttons.
- Nyquist/Bode chart display and operation area (ECM page).

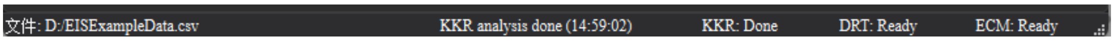
✧ Functional Tabs

The software top bar contains three main functional tabs:

- **KKR**: Kramers-Kronig relation verification
- **DRT**: Distribution of relaxation times analysis
- **ECM**: Equivalent circuit model fitting.

✧ Status Bar Information

The bottom status bar displays:



- Current loaded file path.
- Operation status prompts.
- Operation time display.
- Analysis progress indicator.

2.2. Basic Operational Procedures

I. Data Import

1) Click on **"File"** → **"Import"** → **"Import EIS Data"** in the menu bar.
2) Select the EIS data file (supports CSV, TXT, Excel files).
3) Click "OK" to complete the import.

File Format Requirements:

- Must contain three columns of data: Frequency (Hz), Impedance Real Part, Impedance Imaginary Part.
- Supports files with or without headers.
- Delimiters supported include commas, semicolons, and tabs.

II. Data Preview

1) Check if the data in the left table is correctly loaded.
2) Verify if the Nyquist plot in the central area is displayed normally.
3) Confirm data range and unit settings.

III. Select Analysis Mode

Based on the analysis objective, select the corresponding tab:

- KKR Analysis Mode

1) Set KKR parameters in the right panel:
   a) Select data usage range (All/BelowX/RangeF).
   b) Set cutoff threshold (recommended 0.3-0.7).
   c) Select fitting type (Complex/Real/Imag).
2) Click the "Analyze KKR" button to begin analysis.

- DRT Analysis Mode

1) Set DRT parameters:
   a) Select discretization function type.
   b) Select regularization method.
2) Click the "Analyze DRT" button to begin analysis.

- ECM Analysis Mode

1) Input equivalent circuit formula (e.g., R+(R/Q)+W).
2) Set initial values and constraints for component parameters.
3) Click the "Fit" button to begin fitting.

IV. Result Interpretation

1) View the fitting curve and raw data comparison in the chart area.
2) Analyze fitting parameters and residual data in the left table.
3) Assess fitting quality using statistical indicators (χ^2, AIC, BIC, etc.).

V. Result Export

1) Click on **"File"** → **"Export"** in the menu bar.
2) Select export content:
   a) Data table (CSV format).
   b) Chart images (PNG/SVG/JPG formats).
3) Choose the save path and confirm the export.

2.3. Shortcut Key Descriptions

✧ Global Shortcut Keys

Shortcut Key	Function Description	Usage Scenario
Ctrl + I	Import EIS data	Quickly start a new analysis
F1	Open help documentation	Obtain usage assistance
Ctrl + Q	Exit the program	Safely close the software

✧ Chart Operation Shortcut Keys

Shortcut Key	Function Description	Usage Scenario
Mouse Scroll Wheel	Chart zooming	Adjust view range
Double-click Mouse	Reset view	Restore original display range

✧ Navigation Shortcut Keys

Shortcut Key	Function Description	Usage Scenario
Ctrl + Tab	Switch tabs	Toggle between KKR/DRT/ECM

✧ Usage Recommendations

Recommended Workflow for Beginners

- **First-time Use:** Follow the five-step procedure in Section 2.2 to complete a full analysis.
- **Familiarize with Interface:** Spend 10 minutes exploring the functions of each area.
- **Try Different Modes:** Experience the KKR, DRT, and ECM analysis modes respectively.
- **Select Parameters Based on Prompts:** Choose appropriate parameters based on the tooltip information displayed upon mouse hover.
- **Consult Help:** Use the F1 shortcut key to view detailed help information at any time.

Efficiency Enhancement Tips

- Use shortcut keys instead of mouse operations.
- Utilize the data filtering function to focus on key data ranges.
- Regularly export results to prevent data loss.

Tip: New users are advised to practice with the sample data provided in the "examples" folder in the installation directory before processing actual experimental data.

3. Data Import

3.1. Supported File Formats

AnalyZis supports a variety of common data file formats to meet the output requirements of different instruments and software:

✧ Main Supported Formats

Format Type	Extension	Description	Applicable Scenarios
CSV Files	.csv	Comma-Separated Values file	Most universal data exchange format
Text Files	.txt	Plain text format file	Supports multiple delimiters
Excel Files	.xlsx, .xls	Excel spreadsheet	Directly export data from Excel

✧ Format Compatibility Notes

Delimiter Support: Automatically recognizes commas (,), semicolons (;), tabs (\t), spaces ( ), and other delimiters.

Encoding Support: UTF-8, GBK, GB2312, ASCII, UTF-16, and other common encoding formats.

Precision Support: Supports single and double precision floating-point numbers.

3.2. Data Format Requirements

✧ Basic Data Structure Requirements

1) **Required Data Columns** (in order):
   - Column 1: Frequency (Frequency, Hz)
   - Column 2: Real part of impedance (Z' or Z_real, Ω)
   - Column 3: Imaginary part of impedance (Z" or Z_imag, Ω)

2) **Optional Data Columns:**
   - Phase angle (Phase, °)
   - Magnitude of impedance (|Z|, Ω)
   - Other auxiliary parameters (temperature, voltage, etc.)

✧ File Format Examples

1) **Example 1: CSV file with header**

```
Frequency, Z_real, Z_imag
10000, 0.101, 0.567
1000, 0.101, 0.008
100, 0.234, -0.123
10, 0.567, -0.023
1, 0.789, -0.003
```

2) **Example 2: Text file without header**

```
10000, 0.101, 0.567
1000, 0.101, 0.008
100, 0.234, -0.123
10, 0.567, -0.023
1, 0.789, -0.003
```

3) **Example 3: European format separated by semicolons**

```
Frequency; Z_real; Z_imag
10000; 0.101; 0.567
1000; 0.101; 0.008
100; 0.234; -0.123
```

4) **Example 4: Tab-separated file**

```
Frequency		Z_real	Z_imag
10000	0.101	0.567
1000	0.101	0.008
```

✧ Data Quality Requirements

- **Data Integrity:** No missing values or empty rows.
- **Numerical Validity:** All data must be valid numerical values.
- **Frequency Order:** Recommended to be arranged in descending order (high frequency to low frequency).
- **Data Volume Requirement:** At least 3 valid data points are required.

3.3. Detailed Import Steps

✧ Import Process

1) Click on the main menu: **File** → **Import** → **Import EIS Data**. Or use the shortcut: Ctrl + I.
2) In the file selection dialog, choose the target file and click "Open" to start the import.
3) The software automatically detects the file encoding and delimiter, and recognizes whether there is a header.

✧ Successful Import Notification

- The file path is displayed on the left side of the status bar.
- "Successfully Imported File" is displayed in the middle of the status bar.
- The imported data is displayed in the table on the left side of the KKR page.
- The Nyquist plot is automatically drawn in the central chart area.

3.4. Common Import Issues and Solutions

✧ Issue 1: Encoding Error Causing Garbled Text

Symptoms: Chinese characters appear as garbled text
Solutions:

- Try manually selecting the encoding format: UTF-8 or GBK.
- Save the file as UTF-8 format using a text editor.
- Check if the file is damaged.

✧ Issue 2: Delimiter Recognition Error

Symptoms: Data columns are misaligned or merged.
Solutions:

- Check if the delimiters in the file are consistent.
- Avoid using mixed delimiters.

✧ Issue 3: Inconsistent Data Format

Symptoms: Some data cannot be recognized as numerical values
Solutions:

- Check for non-numeric characters in the data.
- Ensure consistent decimal point format (use a period . instead of a comma ,).
- Remove extra spaces or special characters.

✧ Issue 4: Header Recognition Error

Symptoms: The first row of data is recognized as a header or vice versa.
Solutions:

- Check if the first row contains numerical data.

✧ Issue 5: Abnormal Data Range

Symptoms: Abnormal chart display or obvious data point errors.
Solutions:

- Check if the frequency range is reasonable (typically 10mHz-100kHz).
- Verify if the impedance values are within the expected range.
- Check if the imaginary part is negative (capacitive characteristic).

✧ Advanced Troubleshooting

- **Log File Inspection**

If the import fails, check the log file. Open the log viewer: **Log** → **View Log**, or check the /log/analyZis.log file in the installation directory, and handle it accordingly based on the error information.

- **Example File Testing**

If unsure about the file format, use the example files provided by the software for testing. The example file path is: installation directory /examples/. Compare the format differences between the example files and your own files.

- **Technical Support Contact**

If the issue cannot be resolved, contact technical support through **Help** → **Feedback**. Provide the error log and example files, and describe the specific issue phenomenon and operation steps.

✧ Best Practice Recommendations

- **File Preparation Recommendations**

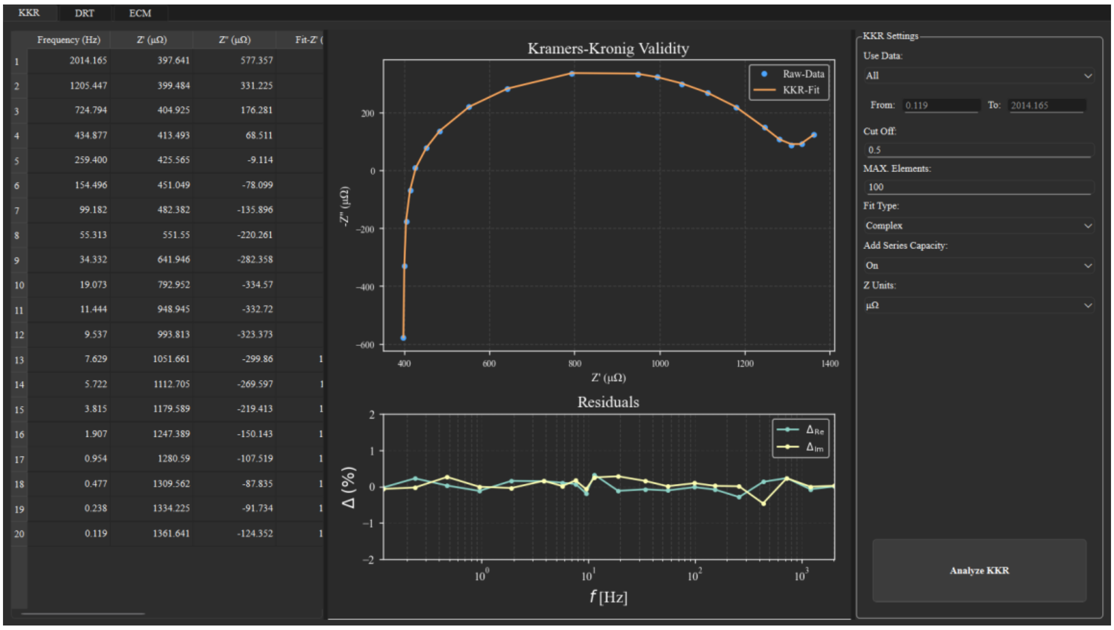
  - **Preprocessing:** Check the file format using a text editor before importing.
  - **Backup:** Back up the original data file before importing.
  - **Standardization:** Use CSV format and UTF-8 encoding whenever possible.
  - **Simplification:** Remove unnecessary columns and comment rows.

- **Data Validation Checks**

  - Verify if the number of imported data points matches expectations.
  - Check if the frequency range is correct.
  - Verify if the impedance values are within a reasonable range.
  - Check if the chart display is normal.

Note: *Correct data import is the foundation for subsequent analysis. It is recommended to ensure the accuracy of data import. For complex issues, contact technical support.*

4. KKR Verification Function



4.1. Introduction to Kramers-Kronig Relation (KKR)

✧ Basic Concept

The Kramers-Kronig relation (KKR) is a fundamental mathematical tool in electrochemical impedance spectroscopy (EIS) analysis, used to verify the **causality**, **linearity**, and **stability** of EIS data. This relation describes the intrinsic mathematical connection between the real and imaginary parts of complex impedance and is an important basis for judging the quality of EIS data.

✧ Mathematical Principle

The basic form of the KKR relation is:

$$Z'(\omega) = \frac{2}{\pi}\int_0^\infty \frac{xZ''(x)}{x^2-\omega^2}dx$$

$$Z''(\omega) = -\frac{2\omega}{\pi}\int_0^\infty \frac{Z'(x)}{x^2-\omega^2}dx$$

Where:

- Z'(ω) is the real part of impedance.
- Z"(ω) is the imaginary part of impedance.
- ω is the angular frequency.

✧ Physical Significance

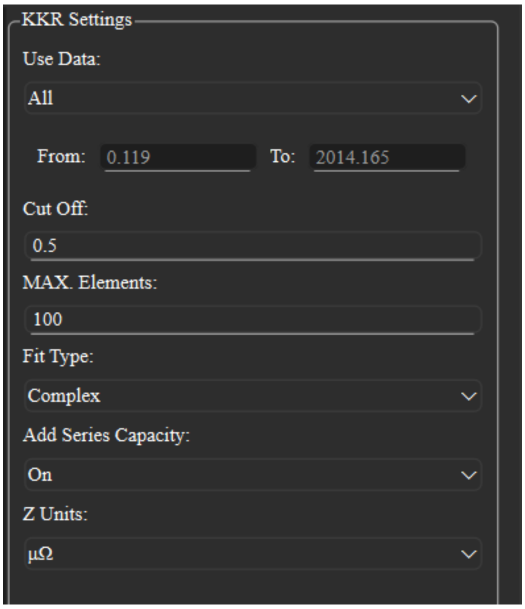
Causality: The system's response cannot precede the excitation.
Linearity: The system's response is proportional to the excitation.
Stability: The system can return to equilibrium after perturbation.

Finiteness: Impedance is finite as frequency approaches zero and infinity.

✧ Application Value

Data Verification: Identify measurement errors and experimental artifacts.
Quality Assessment: Quantify the reliability of EIS data.
Interpolation and Extrapolation: Predict the complete impedance spectrum within a limited frequency range.
Model Verification: Test the rationality of equivalent circuit models

4.2. Parameter Setting Details



✧ Data Range Selection

- **Use Data Options**

Option	Description	Applicable Scenarios
All	Use all frequency data	High data quality, reliable across the entire frequency band
BelowX	Use only data with negative imaginary parts	Exclude the influence of high-frequency inductive effects
RangeF	Custom frequency range	Manually select the optimal data interval

- **Frequency Range Parameters**

From: Lower frequency limit setting (Hz)
To: Upper frequency limit setting (Hz)

✧ Algorithm Parameter Settings

- **Cut Off Threshold（0.0-1.0）**

Function: Controls the strictness of the fit.
Low Value (0.1-0.3): Strict fit, small residuals but may overfit.
Medium Value (0.4-0.6): Balanced fit, recommended for most cases.
High Value (0.7-0.9): Loose fit, strong anti-noise capability.

- **MAX Elements Quantity**

Function: Controls the number of basis functions.
Few (50-100): Fast calculation, suitable for simple systems.
Medium (100-200): Balanced precision and speed.
Many (200-300): High precision, suitable for complex systems

✧ Fit Type Selection

- **Complex Fit**

Simultaneously fits the real and imaginary parts, the most stringent verification standard, recommended for high-quality data.

- **Real Fit**

Fits only the real part data, suitable for situations where the imaginary part has high noise, and calculation speed is faster.

- **Imag Fit**

Fits only the imaginary part data, suitable for situations where the real part has high noise, and for special application scenarios.

✧ Additional Options

- **Add Series Capacity**

On: Add a series capacitor to the equivalent circuit.
Off: Do not use a series capacitor.
Choose based on the specific electrochemical system.

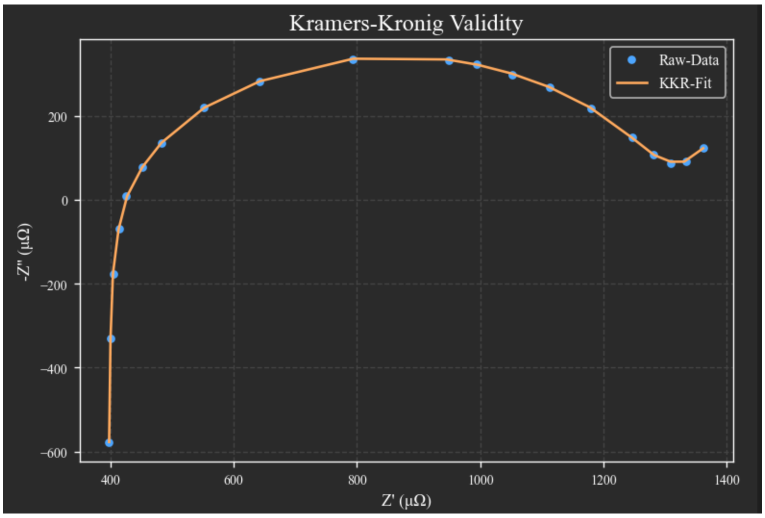
- **Z Units Setting**

μΩ: Microohms, suitable for low-impedance systems.
mΩ: Milliohms, suitable for medium-impedance systems.
Ω: Ohms, suitable for high-impedance systems.

4.3. Analysis Result Interpretation

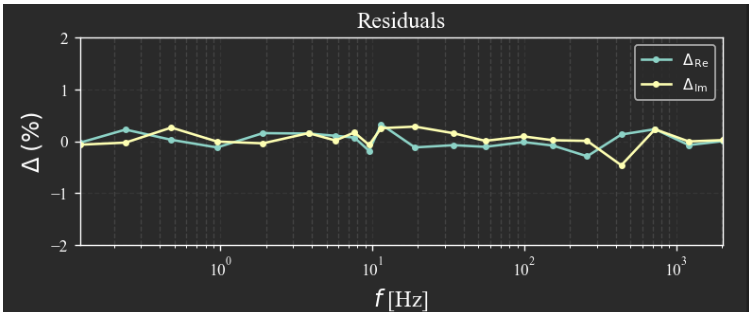
✧ Visual Results

- **Nyquist Plot Display**



Original Data Points: Displayed as blue dots.
KKR Fit Curve: Displayed as an orange curve.
Degree of Coincidence: Reflects the extent to which the data conforms to the KKR relation.

- **Residual Analysis Plot**



Real Part Residual: Green curve, displays the real part fitting error.
Imaginary Part Residual: Yellow curve, displays the imaginary part fitting error.
Error Range: Usually ±5% is considered an acceptable limit.

✧ Result Judgment Criteria

- **Passed KKR Verification (Meets Requirements)**

Residuals are within ±5%, and the fit curve closely coincides with the original data.

- **Failed KKR Verification (Problems Exist)**

Residuals exceed ±5%, and there is a significant systematic deviation. Experimental conditions or data quality need to be checked.

4.4. Application Cases

✧ Case 1: EIS Data Verification for Lithium-Ion Batteries

- To be updated

✧ Case 2: Impedance Analysis of Fuel Cells

- *To be updated*

✧ Case 3: Impedance Verification for Corrosion Systems

- *To be updated*

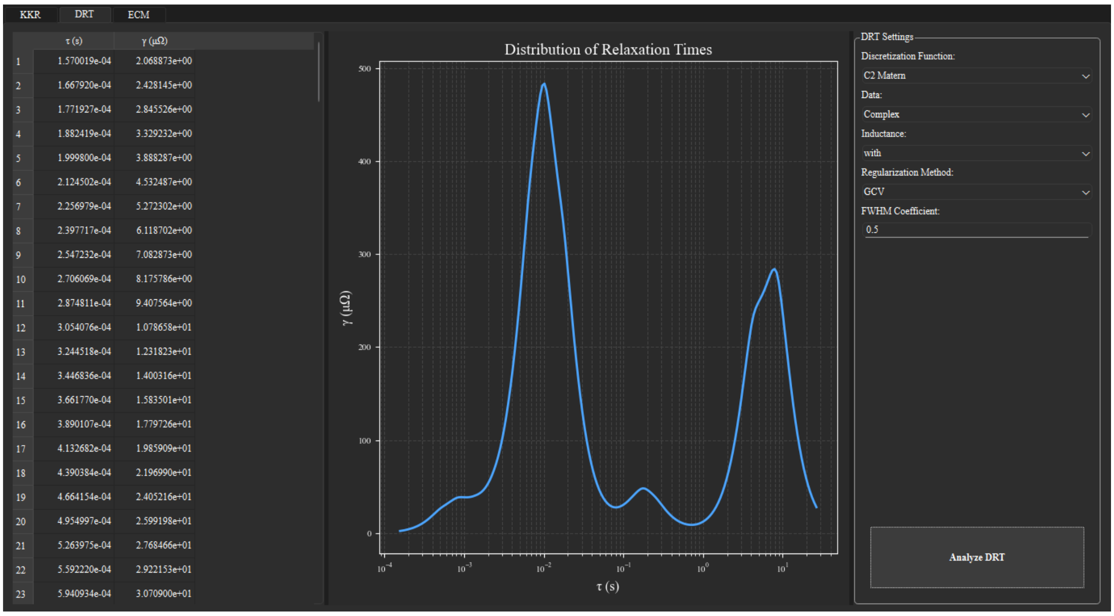
✧ Advanced Application Techniques

- *To be updated*

✧ Notes

- *To be updated*

5. DRT Analysis Function



5.1. Introduction to the Principle of Relaxation Time Distribution

✧ Basic Concepts

Distribution of Relaxation Times (DRT) analysis is a powerful technique for interpreting electrochemical impedance spectra, capable of decomposing complex impedance responses into relaxation processes across different time scales. Compared to traditional equivalent circuit models, the DRT method offers a model-free analytical approach, providing more intuitive insights into the physical and chemical processes within electrochemical systems.

✧ Mathematical Principles

$$Z(\omega) = R_\infty + \int_0^\infty \frac{\gamma(\tau)}{1+j\omega\tau} d(\ln \tau) + j\omega L$$

Among which:

- $Z(\omega)$ is the complex impedance
- R_∞ is the high-frequency resistance
- $\gamma(\tau)$ is the distribution function of relaxation time
- τ is the relaxation time
- L is the inductive component

✧ Physical Significance

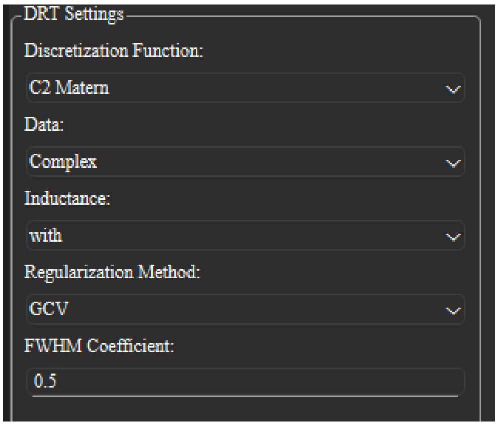
- **Multi-Time Constant Analysis:** Identifying multiple relaxation processes coexisting in the system.

- **Process Separation:** Resolving overlapping impedance arcs into distinct relaxation processes.
- **Kinetic Information Extraction:** Obtain characteristic times and relative contributions of each process.
- **Artifact Identification:** Distinguish between genuine physical processes and measurement artifacts.

✧ Core Advantages

- **Model-Free Assumption:** Does not rely on preset equivalent circuit models.
- **High Resolution:** Capable of distinguishing processes with closely spaced time constants.
- **Intuitive Visualization:** Displays relaxation process distributions in the form of peak-shaped graphs.
- **Quantitative Analysis:** Provides the integral intensity and characteristic time for each process.

5.2. Detailed Explanation of Parameter Settings



✧ Selection of Discretization Functions

- **Gaussian function**

It has good smoothness, strong noise resistance, symmetric peak shape, moderate resolution, and is suitable for most application scenarios.

- **C2 Matern (second order)**

Recommended for use, it balances accuracy and computational efficiency, offers high resolution, good noise resistance, and is suitable for most electrochemical systems.

- **C4 Matern (fourth order)**

High resolution, capable of distinguishing close time constants, sensitive to noise, requires high-quality data.

- **Piecewise Linear Function**

  Most flexible, adaptable to various distribution shapes, but requires more computational resources.

✧ Data Type Selection

- **Complex data**

  Using complete complex impedance information provides the maximum amount of information and is recommended. It requires both real and imaginary data to be of good quality.

- **Real part only**

  Using only the real part of impedance data, suitable for situations with significant noise in the imaginary part, with lower resolution.

- **Imaginary part only**

  Using only the imaginary part of impedance data, suitable for situations with significant noise in the real part, for special application scenarios.

✧ Inductance Processing Options

- **Includes Inductance**

  Retains high-frequency inductance components, suitable for systems with significant inductive effects.

- **Exclude inductance**

  Recommendation: Eliminate the influence of inductance and focus on the electrochemical process.

- **Ignore high frequency**

  Directly discard high-frequency data affected by inductance, simple but may result in information loss.

✧ Regularization method selection

- **Generalized cross-validation**

  Recommendation, use the GCV method to determine parameters

- **L-curve method**

  Use the L-curve to determine parameters

- **Manual setup**

  Manual input of regularization parameters

✧ Regularization parameter settings

When the regularization method is set to "Manual Setting", the regularization parameters can be manually configured:

- **Function**: Controls the smoothness of the fit
- **Small value** (1e-6): Precise fitting but may lead to overfitting
- **Median value** (1e-4): Balances fitting and smoothing
- **Large value** (1e-2): Results are smooth but may underfit

✧ Peak width coefficient setting

- **Function:** Controls the width of the radial basis function
- **Small value** (0.3-0.4): Narrow peak, high resolution but sensitive to noise
- **Medium value** (0.5): Balanced choice, recommended for most situations
- **Large value** (0.6-0.7): Broad peak, strong noise resistance but low resolution

5.3. Application cases

✧ Case 1: DRT analysis of lithium-ion batteries

To be updated

✧ Case 2: DRT Analysis of Fuel Cells

To be updated

✧ Case 3: DRT Analysis of Corrosion System

To be updated

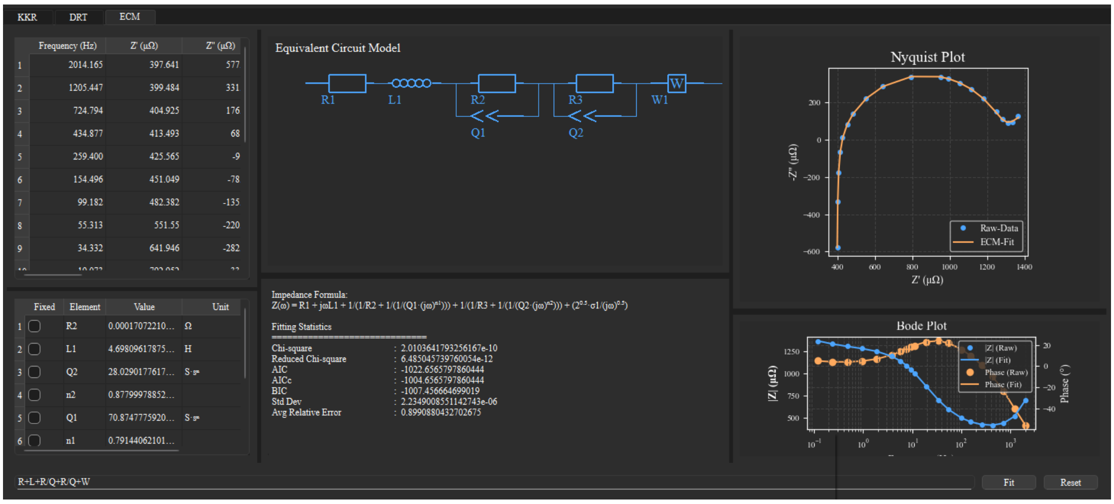
✧ Advanced Analysis Techniques

To be updated

✧ Precautions

To be updated

6. ECM Fitting Function



6.1. Introduction to the Principles of Equivalent Circuit Models

✧ Basic Concepts

The Equivalent Circuit Model (ECM) is the most classic and widely used method in electrochemical impedance spectroscopy analysis. This approach describes the impedance response characteristics of electrochemical systems by constructing equivalent circuits composed of basic circuit elements, transforming complex electrochemical processes into intuitive combinations of circuit components.

✧ Mathematical Foundation

ECM analysis is based on the series and parallel impedance rules in circuit theory:

- Series Impedance:

$$Z_{total} = Z_1 + Z_2 + Z_3 + \cdots$$

- Parallel Impedance:

$$\frac{1}{Z_{total}} = \frac{1}{Z_1} + \frac{1}{Z_2} + \frac{1}{Z_3} + \cdots$$

- **Core Components and Their Physical Significance**

Circuit components	Symbol	Impedance Formula	Physical Meaning
Resistance	R	Z = R	Ohmic resistance, charge transfer resistance
Capacitance	C	Z = 1/(jωC)	Ideal capacitor, interfacial double-layer

Circuit components	Symbol	Impedance Formula	Physical Meaning
			charging
Inductance	L	$Z = j\omega L$	Ideal inductor, wire or electrode inductive reactance
Constant phase element	Q	$Z = 1/(Q\cdot(j\omega)^n)$	Non-ideal capacitance, dispersive interfacial process
Warburg element	W	$Z = 2^{0.5}\cdot\sigma/(j\omega)^{0.5}$	Diffusion impedance, mass transfer limited process

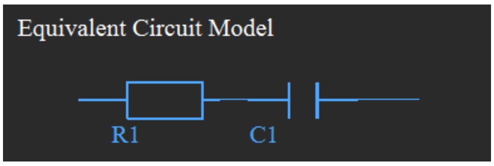
✧ Circuit Syntax Rules

- **Basic Connection Symbols:**

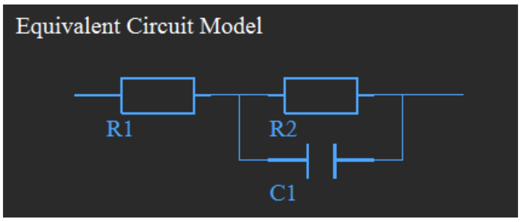
+ : Series Connection
/ : Parallel connection
( ) : Grouping operation, defining operation precedence

- **Formula example**

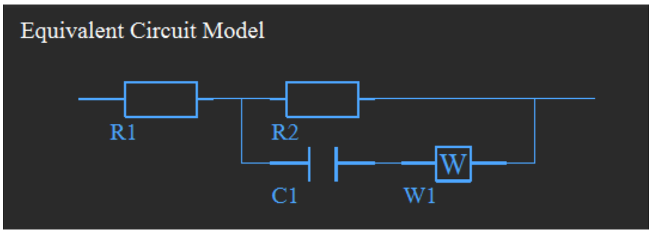
1) Simple RC circuit: R+C



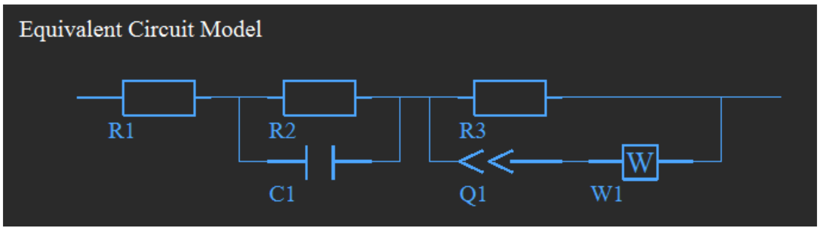
2) Randles circuit: R+R/C



3) Circuit with diffusion: R+R/(C+W)



4) Complex Circuit: R+R/C+R/(Q+W)



6.2. Parameter Fitting and Optimization

✧ Parameter Constraint Setting

- **Fixed parameters**

Known parameters: Fixed known physical constants
Invariant parameters: Parameters fixed and unchanged under varying conditions
Simplified fitting: Reduce the number of parameters to be optimized

✧ Initial value setting strategy

- **Automatic estimation**

Resistance value: Estimated from the high-frequency intercept of the Nyquist plot
Capacitance value: Estimated from the characteristic frequency
n value: Default 0.8-0.9 (CPE element)

- **Manual setting**

Experience value: Based on experience with similar systems
Physical significance: Reasonable range estimated according to theory
Multiple Attempts: Verifying Result Stability with Different Initial Values

✧ Quality Control of Fitting

- **Residual Analysis:** Examining the Distribution of Fitting Errors
- **Parameter Rationality:** Verification of Physical Significance Rationality

6.3. Interpretation of Analysis Results

Impedance Formula:
$Z(\omega) = R1 + 1/(1/R2 + 1/(1/(j\omega C1))) + 1/(1/R3 + 1/((1/(Q1\cdot(j\omega)^{n1}) + (2^{0.5}\cdot\sigma 1/(j\omega)^{0.5}))))$

Fitting Statistics
================================

Chi-square	:	2.0103641793206102e-10
Reduced Chi-square	:	6.485045739743903e-12
AIC	:	-1022.656579786144
AICc	:	-1004.656579786144
BIC	:	-1007.4566646991186
Std Dev	:	2.234900829053838e-06
Avg Relative Error	:	0.8990866866975985

✧ Evaluation of Statistical Indicators

- **Chi-square: Chi-square value (χ^2)**

Measures the degree of difference between observed and fitted values.

Formula:

$$\chi^2 = \sum \frac{\left(Z_{obs} - Z_{fit}\right)^2}{\sigma^2}$$

Evaluation Criteria:

Ideal Value: $\chi^2 \approx$ Degrees of Freedom (n - p)
$\chi^2 \gg$ n-p: Model is inappropriate or errors are underestimated
$\chi^2 \ll$ n-p: Error overestimation or overfitting
Where, n: number of data points, p: number of parameters

- **Reduced Chi-square: Reduced chi-square value (χ^2/ν)**

The chi-square value after considering degrees of freedom, used to compare models of different complexities.

Formula:

$$\frac{\chi^2}{\nu} = \frac{\chi^2}{n - p}$$

Evaluation criteria:

Ideal value: ≈1.0
Acceptable range: 0.5 - 2.0

- **AIC: Akaike Information Criterion**

The difference (ΔAIC) between other models and the model with the minimum AIC value can be calculated to assist in judgment.

Formula:

$$\mathrm{AIC} = 2\mathrm{k} - 2\ln L$$

Where, k: number of parameters, L: maximum likelihood value.

Evaluation Criteria:

ΔAIC < 2: No significant difference between models
ΔAIC = 2-6: Some difference
ΔAIC > 6: Significant difference
Smaller values indicate a better model

- **AICc: Corrected Akaike Information Criterion**

Correct small sample data to prevent overfitting. Use AICc instead of AIC when n/k < 40. When n is sufficiently large, AICc ≈ AIC.

Formula:

$$\mathrm{AICc} = \mathrm{AIC} + \frac{2k \cdot (k+1)}{n-k-1}$$

Where k: number of parameters, n: sample size.

- **BIC: Bayesian Information Criterion**

It favors simpler models more than AIC, is more sensitive to large sample data, imposes stricter penalties on complex models, and is suitable for situations with larger sample sizes. A smaller value indicates a better model.

Formula:

$$\mathrm{BIC} = \mathrm{k} \cdot \ln(n) - 2\ln(L)$$

- **Std Dev: Residual Standard Deviation**

Used to measure the fitting accuracy, it should be comparable to the instrument's measurement precision. A smaller value indicates a more precise fit, and the ideal value should be close to the measurement error.

Formula:

$$\boldsymbol{\sigma} = \sqrt{\frac{\Sigma(Z_{obs} - Z_{fit})^2}{n-p}}$$

- **Avg Relative Error: Average Relative Error**

Used for fitting quality evaluation.

Formula:

$$\mathrm{ARE} = \frac{1}{n} \times \sum \left| \frac{Z_{obs} - Z_{fit}}{Z_{obs}} \right| \times 100\%$$

Evaluation Criteria:

< 5%: Excellent
5-10%: Good
10-20%: Acceptable
> 20%: Needs Improvement
Comprehensive consideration of real and imaginary part errors

✧ Graphical Evaluation

- **Nyquist Plot Fitting**

Data Points: Experimental Measurements (Scatter Points)
Fitted curve: Model calculated values (solid line)
Degree of overlap: Visually displays the quality of fit

- **Residual analysis**

  Real part residual: (Z'_exp - Z'_fit)/Z'_exp
  Imaginary part residual: (Z"_exp - Z"_fit)/Z"_exp
  Acceptable error: Generally <5%

- **Interpretation of the Physical Meaning of Parameters**

  Resistor Component (R)
  - **Rs:** Solution resistance, reflecting the conductivity of the electrolyte
  - **Rct:** Charge transfer resistance, reflecting reaction kinetics
  - **Rfilm:** Film resistance, reflecting surface film impedance

  Capacitive elements (C, Q)
  - **Cdl:** Electric double-layer capacitance, reflecting the electrode/solution interface
  - **Q**: Constant phase element, reflecting non-ideal capacitive behavior
  - **n value**: Dispersion coefficient (0-1), reflecting interface uniformity

  Diffusion element (W)
  - **σ:** Warburg coefficient, reflecting the diffusion rate

- **Circuit model validation**

  KKR Verification
  - Check if the fitting results comply with the Kramers-Kronig relations
  - Verify the causality, linearity, and stability of the model

  Physical plausibility
  - Whether parameter values are within physically possible ranges
  - Whether temperature/concentration dependencies align with theoretical expectations
  - Whether it is consistent with the results of other measurement techniques

  Model comparison
  - Compare the goodness of fit of different circuits
  - Model selection using AIC/BIC
  - Avoid over-parameterization (overfitting)

6.4. Application cases

✧ Case 1: ECM Analysis of Lithium-ion Batteries

To be updated

✧ Case 2: ECM Analysis of Fuel Cells

To be updated

✧ Case 3: ECM Analysis of Corrosion System

To be updated

✧ Advanced Application Techniques

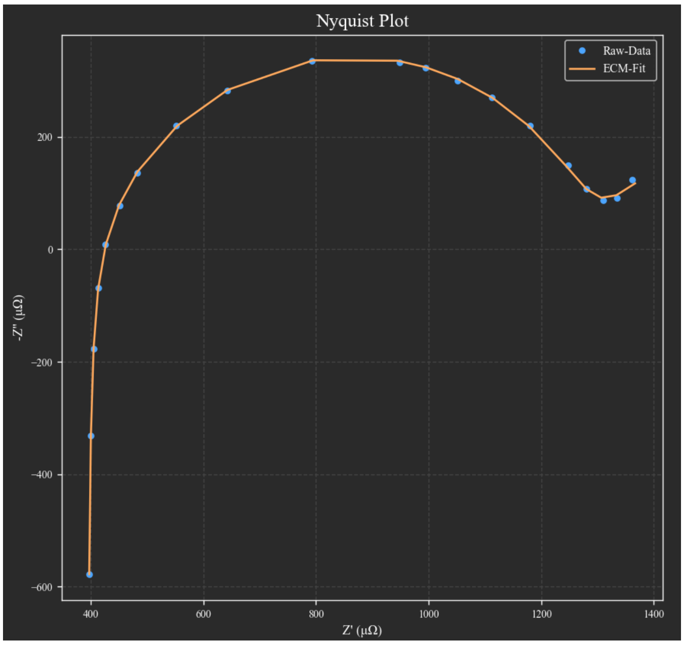
To Be Updated

✧ Precautions

To Be Updated

7. Data Visualization

7.1. Nyquist Curve Operation Guide



✧ Basic Concepts

The Nyquist plot is the most commonly used visualization tool in electrochemical impedance spectroscopy analysis, with the real part of impedance (Z') as the horizontal axis and the negative imaginary part (-Z") as the vertical axis, intuitively displaying the characteristic shape of the impedance response.

✧ Interactive Operation Function

- Zoom Control

Mouse Wheel: Zoom centered on the cursor for detailed viewing of specific areas
Double Click: Reset to the original view and restore the global perspective

✧ Display

- Data Series

Raw Data: Scatter Plot Display
Fitted curve: Line graph display
Residual display: Shows the distribution of fitting residuals

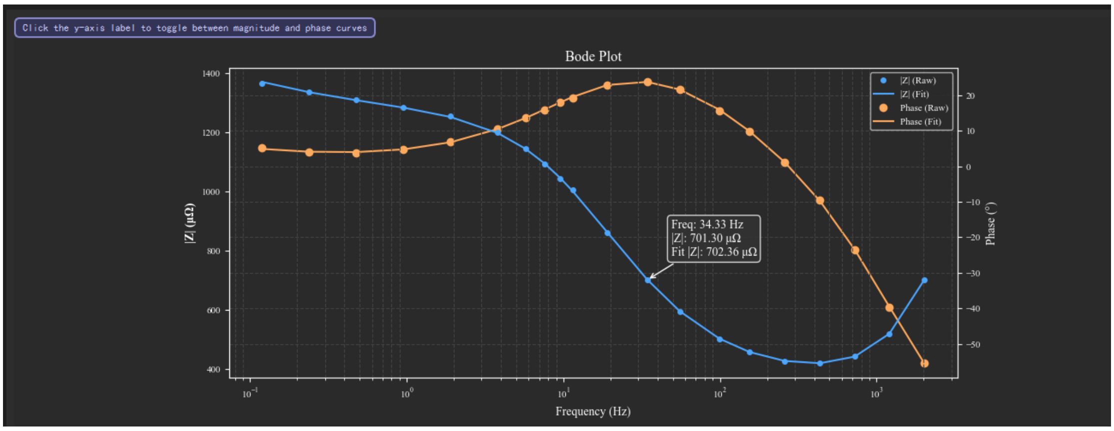
✧ Data point interaction

- Hover Tooltip

Auto Display: Shows the most recent data point information when hovering

Information Content: Frequency, Real Part, Imaginary Part, Residual

7.2. Bode Plot Operation Guide



✧ Introduction to Chart Types

The Bode plot uses frequency as the horizontal axis (logarithmic scale) to display the variation of impedance magnitude (|Z|) and phase angle (θ) with frequency.

- **Amplitude-frequency characteristic diagram**

  Vertical axis: Impedance magnitude |Z| (logarithmic scale)
  Display content: Variation of impedance magnitude with frequency
  Application: Identifying Dominant Processes in Different Frequency Ranges

- **Phase-Frequency Characteristic Diagram**

  Vertical Axis: Phase Angle θ (Linear Scale)
  Display Content: Phase vs. Frequency
  Application: Determining Capacitive/Inductive Characteristics of Processes

✧ Multi-Axis Display Control

- **Dual Y-axis configuration**

  Left Y-axis: Impedance magnitude |Z| (logarithmic scale)
  Right Y-axis: Phase angle θ (linear scale)
  Auto Alignment: Automatic optimization and alignment of dual-axis scales

- **Axis Activation Control**

  Click to Toggle: Click on axis labels to activate the corresponding axis
  Visual Feedback: Activate axis label highlighting
  Zoom Synchronization: Synchronous adjustment of dual Y-axes during X-axis zoom

✧ Frequency Range Management

- **Logarithmic coordinate characteristics**

Automatic scaling: Automatically sets the logarithmic scale based on the data range
Scale density: Controls the density of major and minor tick marks

- **Range Optimization**

Auto-Adaptation: Automatically selects the optimal display range based on data
Key Areas: Can focus on specific frequency intervals
Full Range Display: One-click to show the complete frequency range

✧ Data Comparison Function

- **Multiple Data Sets Overlay**

Simultaneous Display: Multiple sets of Bode plots can be displayed on the same chart.
Color Differentiation: Different data series are distinguished by different colors.
Legend Management: Automatically generates an interactive legend.

- **Difference Display**

Difference Mode: Displays the differences between two sets of data
Ratio Mode: Shows the impedance change ratio
Reference Line: Add baseline reference comparison

8. Data and Chart Export

8.1. Analysis Data Export

✧ Export Format

- CSV Format

Strong versatility, text-based format, moderate file size, maintains data precision, supports scientific notation, and is compatible with almost all software.

Example of file structure:

```
Frequency (Hz),Z' (μΩ),Z'' (μΩ),Fit-Z' (μΩ),Fit-Z'' (μΩ),Res-Z' (%),Res-Z'' (%)
2014.165,397.641,577.357,397.629,577.205,0.00,0.02
1205.447,399.484,331.225,399.868,331.243,-0.07,-0.00
724.794,404.925,176.281,403.898,175.263,0.23,0.23
434.877,413.493,68.511,412.950,70.451,0.13,-0.46
259.400,425.565,-9.114,426.798,-9.144,-0.29,0.01
```

✧ Data content

- KKR data export

Complete data: includes raw data, fitting results, and residuals

- DRT data export

Complete data: includes relaxation time and relaxation time distribution function

- ECM Data Export

Metadata: Analysis parameters, raw data, fitted data, errors
Statistical Metrics: χ^2, AIC, BIC, and other goodness-of-fit indicators
Parameter Information: ECM Formula, Impedance Formula, Fitted Parameter Values
Unit Information: Unit Labels for All Data

8.2. Chart Export

✧ Export Format Selection

- Image Format

Format	Resolution	File Size	Applicable Scenarios
PNG	High (300-600 DPI)	Medium	Paper publication, report creation
SVG	Infinite scaling	Small	Vector editing, web usage
JPEG	Adjustable	Small	Webpage preview, quick sharing

✧ Best Practice Recommendations

- **Visualization Strategy**

  Select Appropriate Chart Types: Choose Nyquist or Bode plots based on analysis objectives
  Optimize Display Range: Adjust coordinate ranges to highlight key features
  Use consistent styles: Maintaining style consistency across multiple charts facilitates comparison

- **Interactive techniques**

  Make full use of zooming: Combine global view with detailed inspection
  Use Data Tips: Quickly obtain data information by utilizing hover prompts.

- **Export Optimization**

  Choose the Appropriate Format: Select the best file format based on the intended use.
  Balance quality and size: Achieve a balance between image quality and file size
  Include necessary information: Ensure the exported chart contains all essential information

Note: *Effective data visualization is a key aspect of impedance analysis. It is recommended to optimize the chart display to make data features clearer and more comprehensible.*

9. Advanced Features

9.1. Unit System Settings

- Unit System Options

Unit	Symbol	Conversion relationship	Applicable Scenarios
Micro-Ohm	μΩ	1 μΩ = 10^{-6} Ω	Low impedance systems (batteries, supercapacitors)
Milliohm	mΩ	1 mΩ = 10^{-3} Ω	Medium impedance system (fuel cell)
Ohm	Ω	Base unit	High impedance systems (coatings, corrosion studies)

- Unit Conversion Function

Automatic Conversion: Adjusts all displayed values automatically based on selection
Data Consistency: Ensure analysis results are consistent with unit settings

- Scope of Unit Settings Impact

Data Display: All impedance values in tables and charts, including KKR, DRT, and ECM pages
Analysis Results: Fitting parameters and statistical metrics
Export Content: Unit consistency for all exported data

9.2. Multilingual Support

- Supported Languages List

Language	Code	Level of Support	Features
English	en	Full support	Default language, accurate terminology
Simplified Chinese	zh	Full support	Localization of Professional Terminology

- Real-time Language Switching

Menu Selection: Switch directly through the language menu
Configuration File: Modify the default language by editing the /config.ini/config.ini file in the program directory

- Switch Effect

Immediate Effect: No software restart required
Complete Switchover: All interface elements switch simultaneously
Memory Function: Remember the user's language preference

9.3. Log Management

- Log Level Settings

Level	Description	Applicable Scenarios
DEBUG	Debug Information	Development testing, detailed operational information
INFO	General information	Normal operation log, recommended for production environment
WARNING	Warning message	Potential Issue Alert
ERROR	Error Message	Operation failed, attention required
CRITICAL	Critical error	System severe failure

- Log File Management

Rotation by Size: Maximum single file size 2MB
Backup Count: Retain the latest 5 backup files

- Built-in log viewer

View logs through the log menu to monitor the latest log information in real-time, including complete content at all log levels, and export log files to a specified directory for storage.

- Log file location

Default path: Installation directory /log/analyZis.log

10. Contact

If you encounter any difficulties while using the AnalyZis EIS analysis software, or have any suggestions and feedback, please contact us.

- Email:
  Support@AI-EIS.com
- Website:
  https://www.ai-eis.com/
- Feedback:
  https://www.ai-eis.com/AnalyZis_feedback.html
- Address:
  Room 806, Building B, Lingang Science and Technology Center, No. 333 Haiyang First Road, Lingang New Area, China (Shanghai) Pilot Free Trade Zone

Please follow our official account and add the corporate WeChat contact to receive the latest product information and technical support as soon as possible.

WeChat Official Account

Corporate WeChat

Copyright Information

Copyright Notice

Product Information

Software Name: AnalyZis EIS Analysis Software
Version: V1.04.00R
Document Version: 1.01
Release Date: October 12, 2025
Document ID: AIEIS-ANZ-DOC-20251012-V1.01

Trademark Statement

AnalyZis® is a registered trademark of Shanghai Zhiyuan Suanneng New Energy Technology Co., Ltd.
All other trademarks, trade names, service marks, and product names mentioned in this document are the property of their respective owners.

License Information

I. Usage License

This user manual is to be used only with a legally authorized copy of AnalyZis software. Any user who installs or uses this software thereby agrees to comply with these license terms.

II. Copying License

Permission is granted to make copies of this manual for backup purposes, provided that all copies include the complete copyright notice and ownership information.

III. Prohibited Actions

The following actions are strictly prohibited:

- Removing or altering any copyright notices or trademark logos
- Reverse engineering, decompiling, or disassembling the software
- Unauthorized distribution, rental, lending, or sublicensing

Limitation of liability

I. Disclaimer

This software and documentation are provided "as is" without any express or implied warranties, including but not limited to the implied warranties of merchantability, fitness for a particular purpose, and non-infringement.

II. Scope of Liability

Under no circumstances shall Shanghai Zhiyuan Suanneng New Energy Technology Co., Ltd. be liable for any direct, indirect, incidental, special, consequential, or punitive damages arising from the use or inability to use this software and documentation, even if advised of the possibility of such damages.

III. Technical Updates

The company reserves the right to modify product specifications and documentation content at any time without prior notice.

Important Notice

I. Export Control

This software and technical data are subject to Chinese export control laws and regulations. Users agree to comply with all applicable export control laws and regulations, and shall not directly or indirectly export or transfer the software or technical data to any country or region subject to export control restrictions, or to any restricted end-user.

✧ *Special thanks to all partners and users who contributed to the development and testing of AnalyZis software.*

✧ *The content of this document is subject to change without notice. Please visit the official website regularly for the latest information.*