ZMAN ver2.2

User's Manual

May 2010

www.edaq.com

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Contents

Chapter 1 Overview

ZMAN is a scientific application for Electrochemical impedance analysis and modeling.

With ZMAN, you can integrate a series of impedance measurements and control parameters into a single file, and then present them in sophisticated 2D and 3D graphs including the familiar Nyquist plots and Bode diagrams.

With its powerful equivalent circuit model editor, you can easily add arbitrary circuit components, expressed by complex functions, to build and manage your own equivalent circuit models.

ZMAN's special equivalent circuit search engine lets you search for an appropriate equivalent circuit model which best fits the raw impedance spectrum from pre-defined and user-defined models.

In addition, ZMAN helps you fit model parameters with the equivalent circuit fitter employing the Levenberg-Marquardt (LEVM) algorithm and to compare the best-fit result against raw data in graphical form. In fitting impedance series, you can use previous best-fit parameters as initial values for fitting the next impedance spectrum.

A. What is new in ZMAN 2.2

ZMAN is loaded with features that will enable you to systematically analyze impedance data. ZMAN offers various types of graphical displays including Nyquist Plot, Bode Diagram, Parameter Plot and 3D Plots. There are powerful fitting modules supporting built-in equivalent circuits and user-defined libraries.

These exciting features will help you manage and analyze your impedance data in a more productive way than ever before.

B. History of ZMAN 2.2

- Upgrade from ZMAN 2.1
- ZMAN 2.1
- ZMAN 2.0
- Upgrade from ZMAN 1.1

C. Major New functions

➢ in ZMAN version 2.2

- Interpolate Bad data
- Black-Nichols Plot
- 3D graph setting option
- Improved Model editor
- Application Model library for automatic searching
- Parameter Simulation of model
- Genetic analysis option for fitting
- Automatic initial guessing
- Trace movie function on fitting

➢ in ZMAN version 2.1

- Data analysis for WonATech data format (WDF, WIS file) without a license code. WDF file extension is from WEIS system, WIS file extension is from Z# and Z100 systems
- Data editing
- Circle fitting
- Add/remove element parameter
- Add/remove model parameter
- Impedance E,M,Y,Z in polar Admittance Modulus Dielectric constant Data display

D. System requirements

In order to run ZMAN, you must ensure that your computer meets the following software and hardware requirements:

Operating System: Microsoft Windows XP, 2000, Vista, or Windows 7 (32Bit version)
Processor: Intel Pentium 4 or equivalent
RAM: 512MB
Display: 1280 x 1024 recommended. If you have a lower resolution monitor, you can use ZMAN by maximizing window size.
Internet: An internet connection is required for registration

E. Installation and Setup

Installation and setup is performed by running "setup.exe" or "install.exe" from the ZMAN software CD.

The ZMAN software will then be installed, along with the National Instruments libraries.

After installation, you can run ZMAN by going to the Start Menu, All Programs, WonATech, ZMAN 2.2 and clicking ZMAN.

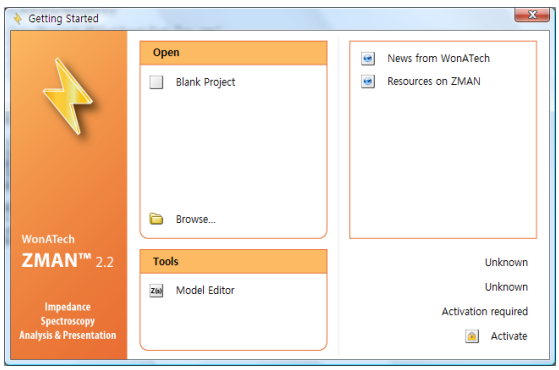

Figure 1. Intro Menu without license(Before license Request)

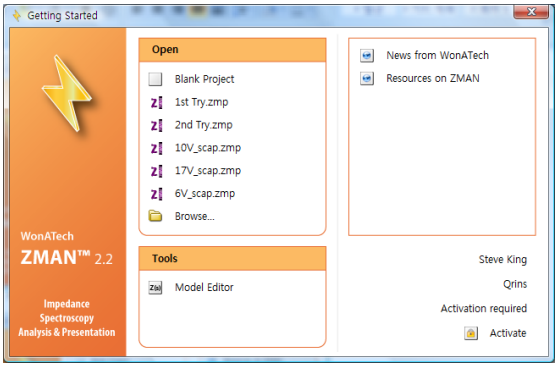

Figure 2. Intro Menu without license(After license Request)

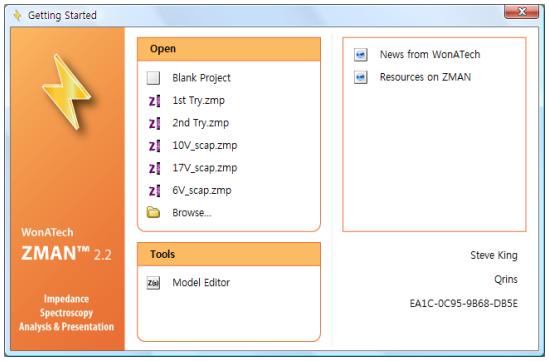

Figure 3. Intro menu with licensed

The XMAN2.2 Introductory menus are shown in the figures above.

You can select a blank project, select a recent project or you can browse for a specific file by clicking the Browse button.

If you only want to edit/create a model, you can enter Model editor directly.

If you select a blank project, the following window will appear.

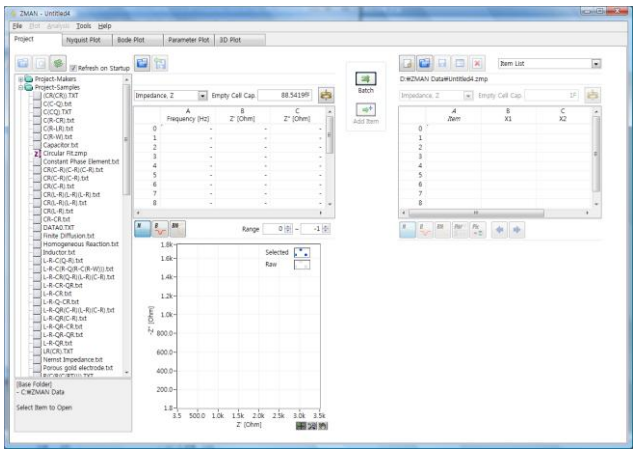

Figure 4. ZMAN starting

If you have purchased ZMAN and have not activated the ZMAN license, you will need to send some information to WonATech in order to receive a valid license code.

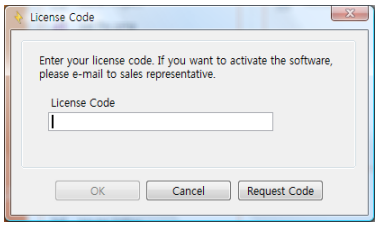

Figure 5. License Code Entry

Click the "Send e-mail" button, and fill in your registration details:

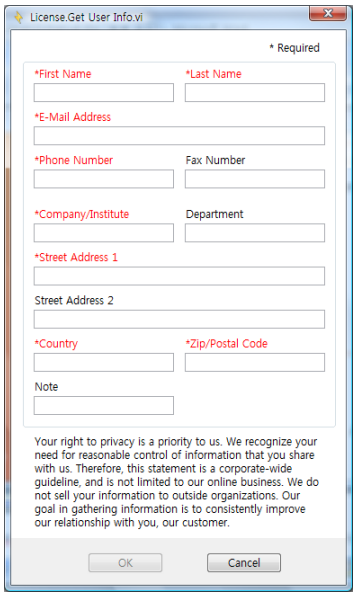

Figure 6. License code application form

If you have not purchased ZMAN and want to evaluate the software, click the "Cancel" button.

If you have purchased ZMAN, then fill in the required information and click the "OK" button.

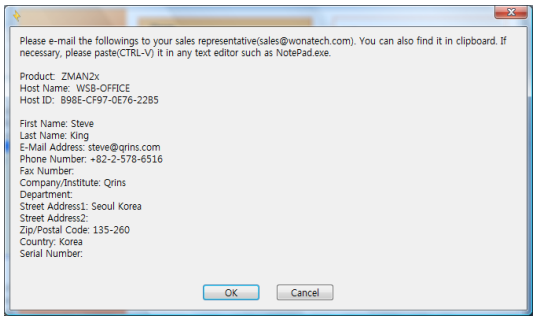

Figure 7. Send registration email

If you click the "OK" button, the program will automatically e-mail this information to WonATech to obtain a license code. If your PC is not connected to the internet, please paste (Ctrl+V) the information into a text editor and email it to sales@WonATech.com. You will then receive the license code for ZMAN by email. Until the license code has been entered into ZMAN, you can only use it with WonATech generated data.

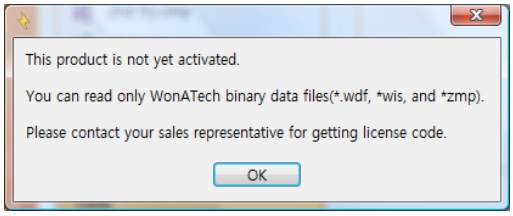

Figure 8. License notice

F. Licensing Note

A ZMAN license code is required for each PC you use it on. You must install ZMAN into the PC you want to use ZMAN software for 3rd parties data analysis. Without a valid License code, you can use ZMAN for WonATech generated data in any PC with full functions.

G. Known Bug

ZMAN uses Microsoft Common Control to open a file; however, the file open dialog is not loaded in some machines. It is caused from a licensing issue of the ActiveX control. The easiest way to fix it is to install Microsoft Visual Studio or Visual Basic.

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If you write to us about a problem, please provide as much information as possible.

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WonATech Co., Ltd warrants to the original user of this product that it shall be free of defects resulting from faulty manufacture of the product.

WonATech Co., Ltd makes no warranties regarding either the satisfactory performance of ZMAN package including the software encoded in this product or the fitness of the system for any particular purpose.

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Chapter 2 About ZMAN

The basic concepts and features of ZMAN™ are shown in the figure below.

In this section, you will learn about the main features and functions of ZMAN. To get an overview of some of the features of the software, follow these steps:

1. Open a data file. Refer to EIS **Data File** for details. You can use your EIS data file or importing 3rd parties data file.

2. Edit your data file. You may edit bad data or combine some series measurement for ZMAN analysis. Refer to **Preview data file** for details

3. Project concept. You can use **Project function** to manage your series of data files measured with max 3 control variables. Refer to Project for details

4. Check validity using the Kramers-Kronig relation. For details, see **Kramers-Kronig Consistency**. However, this is not a general procedure used to analyze impedance data.

5. Using the Levenberg-Marquardt algorithm, best fit the data to an Equivalent Circuit which is defined and selected in the Equivalent Circuit Model Editor. Refer to **Modeling**

6. Try circular fitting for your Nyquist plot's shape having semi-circle. Refer to **Circular fitting** for details

7. You can add or subtract some element or model from your data. Refer to **Manipulate element or Model** for details

8. You can create/manage your own model or models in libraries. Refer to **Equivalent Circuit Model Editor**.

9. When you are uncertain what is an appropriate equivalent circuit or you are not familiar with equivalent circuits, you can use the ZMAN automatic Search Engine to find possible choices. Refer to **Automatic Model Searching** for details.

10. Plot the data file. Refer to **Impedance Data plot** for details. You may plot raw data with KK checked results or best fit results in various types of graphs. Best fit parameters are plotted against control variables.

11. There are many type of graph handling for impedance data presentation. Refer to **Graph** for details

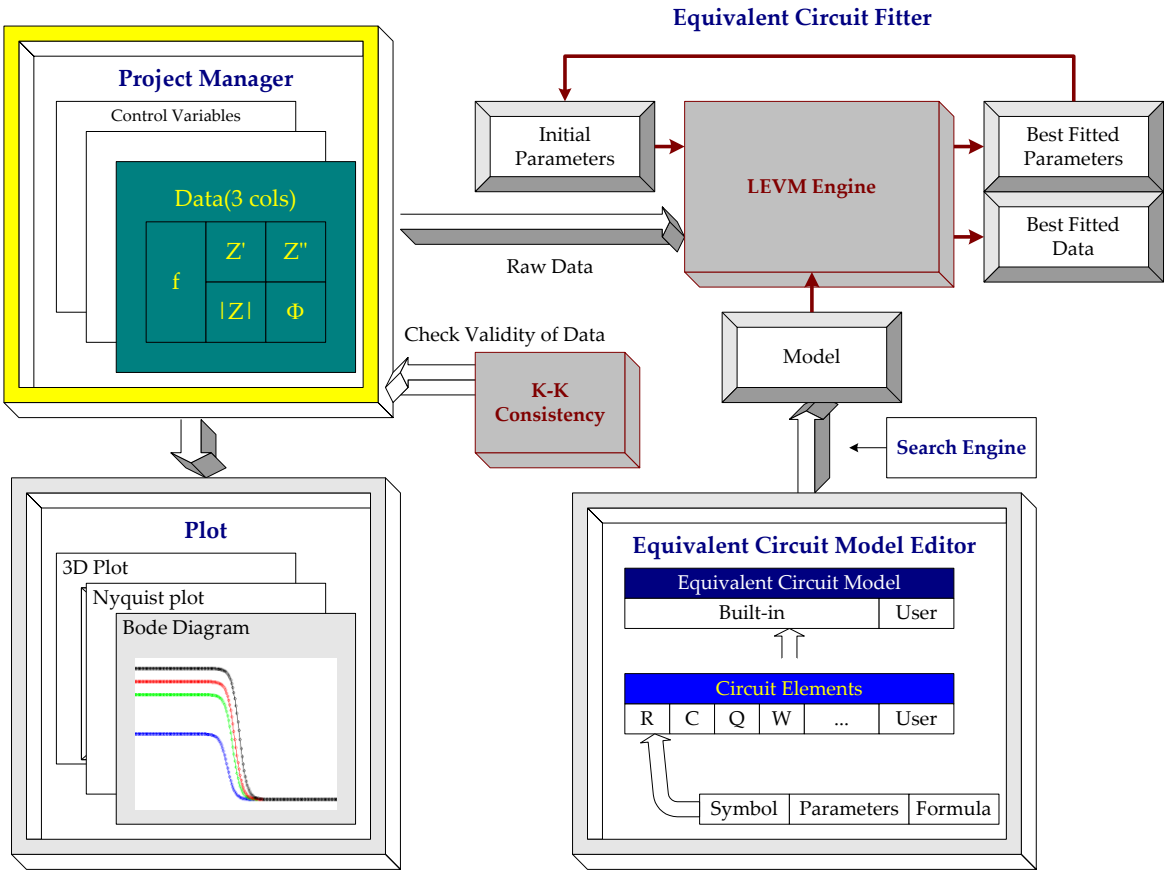


Figure 9. ZMAN Diagram

Chapter 3 EIS DATA FILE

ZMAN uses a project concept. Each impedance data file(s) can be transferred to project file.

Data files can only be analysed if they have first been transferred to a project.
A Project can be handled as single file or multiple files.

The main rationale for the use of the project concept is to allow analysis of data sets obtained during varying experimental conditions.

In the Project tab, there are 3 sections.

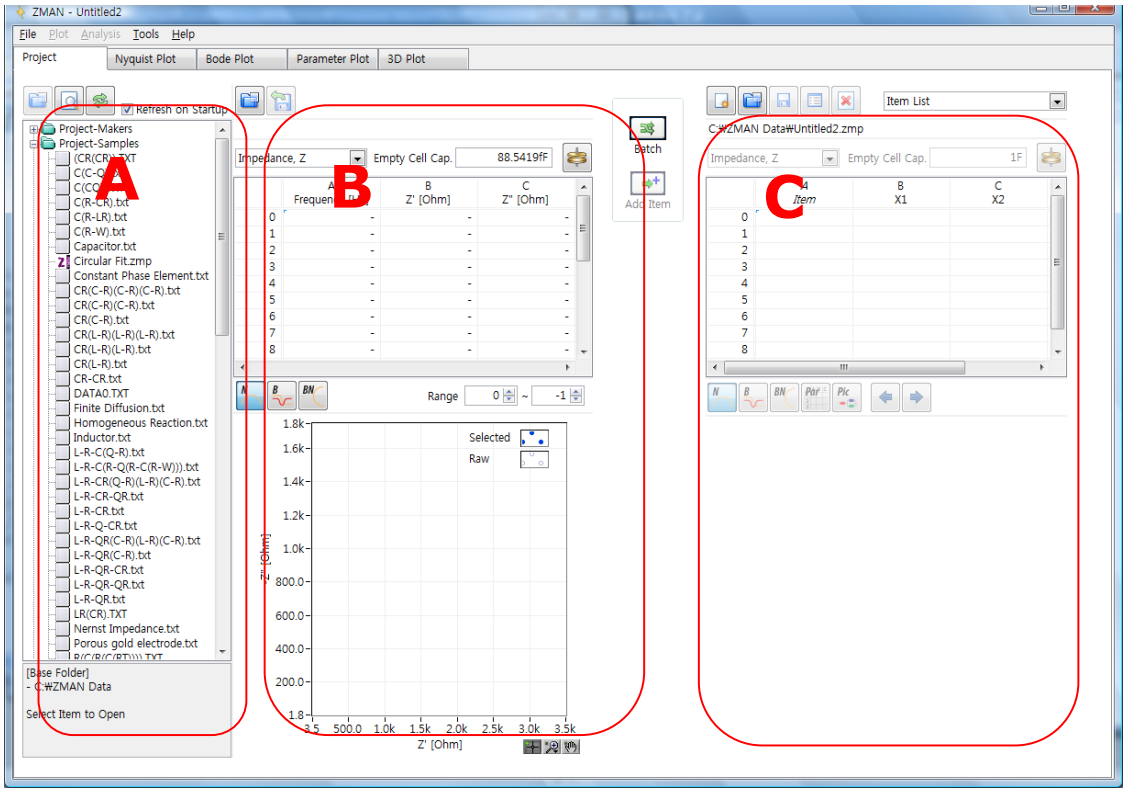


Figure 10. Main windows structure

You can select raw data as an individual file or you can group several data together and save them in a ZMAN project file in Project Tab. ZMAN Project files end with the extension ***.zmp**.

There are 3 sections as shown in Fig 10.

"A" section: Data files handling
"B" section: Data file Preview
"C" section: Project file handling for ZMAN data analysis

A. Browse data files

1. Base folder selection

ZMAN shows a list of data files which can be used in ZMAN. This file list can differ by licensing type. Displayed data files are located in a base folder which user can define. You may need to select a folder which contains EIS data files. To select a folder, click the right mouse button at "A" section in Figure 10. The following pop up menu will appear, see Fig 11.

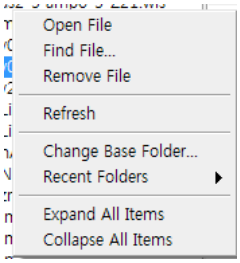


Figure 11. Data file handling pop up menu

You can change the base folder by selecting "Change Base Folder.." on pop up menu, ZMAN will show file list including subsidiary folders.

If you check on Browse at Start Up , ZMAN will show the files which you set as the base folder last time you open the ZMAN program.

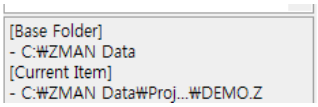


Figure 12. Base folder display

The current base folder at bottom of the Base folder display, see Fig 13.
If you select the file, you can also view base folder file information.

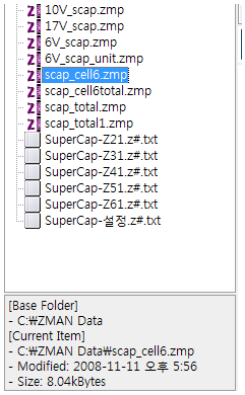


Figure 13. File information

2. Recent folders

You can easily change highest path using Recent folders. Recent folders will display folders which you previously set as a base folder.

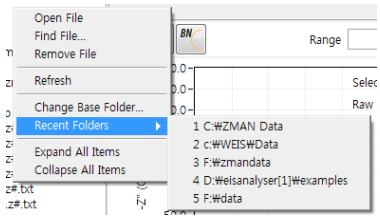


Figure 14. Recent folders

3. Refresh list

If you select Refresh or click refresh button  , data file list is updated.

4. Expand All Items

You can display All EIS data files in subsidiary folders when you select "Expand All item". Generally subsidiary folder's EIS data can be seen when you click this folder.

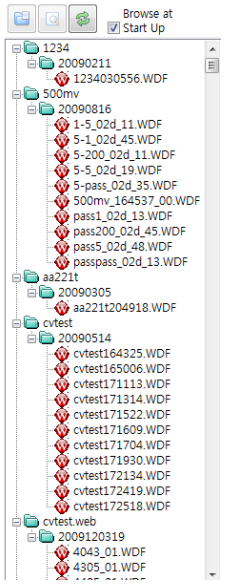


Figure 15. Open All items

Note: WDF file is not all for EIS data.

5. Collapse All Item

If you select this, you can view just the base folder data list. Sub folder's data list will be collapsed. You can return to the normal display by selecting "Collapse All items".

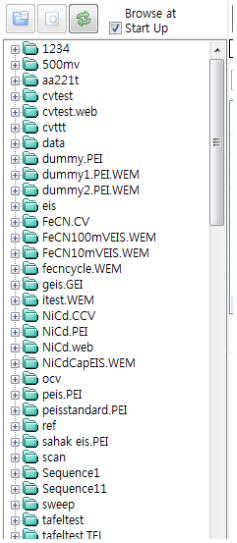


Figure 16. Collaps All items.

B. File Menu

6. Find File

You can find a file using "Find File function".

To use this function, you can click  icon or select submenu on file list section "A"

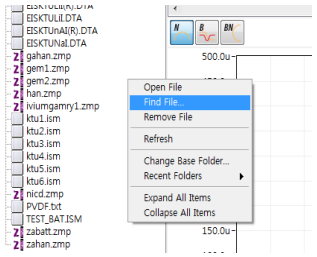


Figure 17. File list submenu

The following menu will become available.

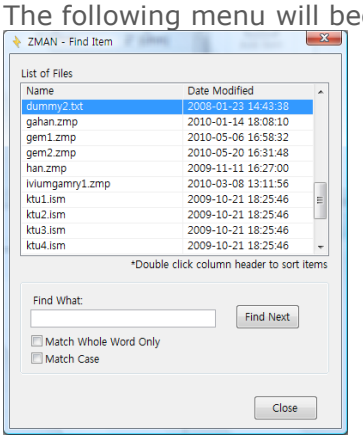


Figure 18. Find item menu

If you want to sort by file name or date, double click on the appropriate column header.

7. Remove file

You can erase data file on hard disk.

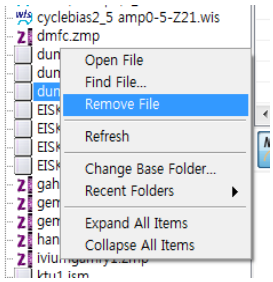


Figure 19. Remove file

Select data file which you want to erase and select "Remove file".

The following warning message box will appear and ask for confirmation.

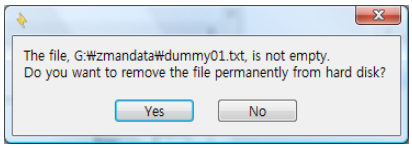


Figure 20. Warning message

C. Data file Open

You can load data file(s) into ZMAN using two methods.

8. Without License Code:

You can select data file in section"A" by double clicking on the file name, you can then see, EIS data preview of this selected file. If this is the file you want to load into Project for data analysis, click "add" button. You can then see selected files information in section "C". ZMAN can load the data files (zmp, wdf etc) which come from WonATech or EDAQ product directly without a license code. If you wish to load ASCII file produced by 3rd party EIS products you will then need to purchase and obtain a ZMAN license code.

a) Single EIS data set

If a data file is a single EIS data set, Double Click on the data file in section "A" Then you can see data preview in section "B"

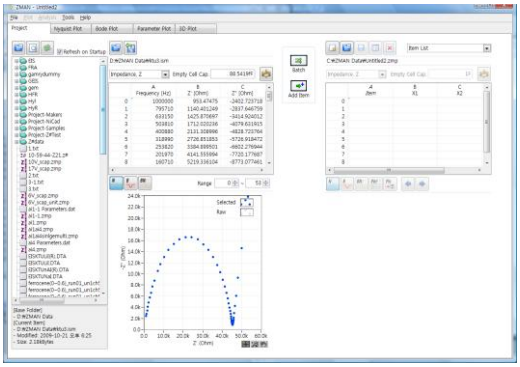


Figure 21. Data preview

b) Multiple EIS data set

WDF file (WEIS data file). If your WDF data file includes multiple EIS data sets (e.g. Series measurement etc). Double click on data file name on section "A".

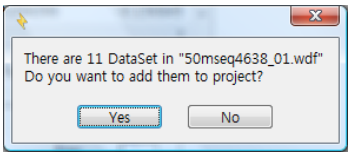


Figure 22. Multiple data loading

If you inserted Cycle marker to produce the above sequence file, the box above will appear. Click "Yes" then multiple EIS data will be split automatically and loaded in Project part (Section "C")

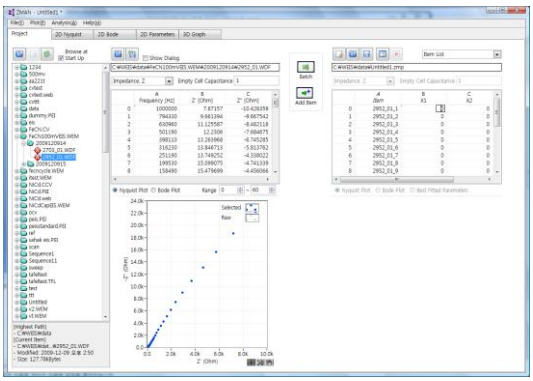


Figure 23. Parameter value editing

If you do not want to use all EIS data sets, click "No" and the select box will appear.

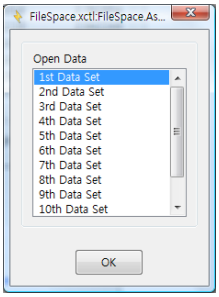


Figure 24. File select

You can then select one EIS data set for analysis.
Other data file:
If your data file contains multiple EIS data sets, you can split the file into seperate EIS data sets using the data range function.

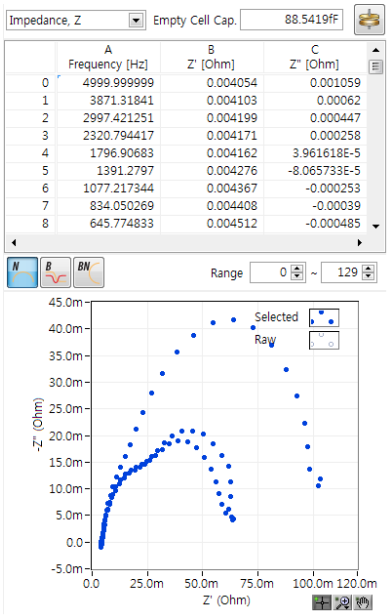


Figure 25. Data file containing multiple EIS data set

c) Project file

Double click on project data file (zmp) name in section "A"
Then project data will be loaded in section "C"

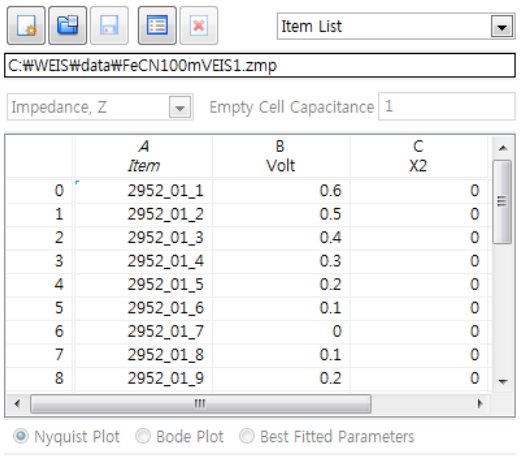


Figure 26. Parameter editing example

9. With License Code

Reading of ASCII and 3rd Party files requires a License Code to be obtained from WonATech.

a) Direct reading 3rd parties data(Needs License Code)

ZMAN read Zahner Data file(*.ism), Autolab Data file(*.dfr) directly without text file importing menu.

b) Ascii file and 3rd party's data (Needs License Code)

Select an ASCII file(needs license code) to analyze. You may change extensions among Data File (*.dat), Text File(*.txt) Solartron Data file(*.z)and Gamry Data File(*.dta). ZMAN supports ASCII data file containing several lines of header, which are automatically recognized and ignored in ZMAN, and three successive columns with numbers such as frequency, real and imaginary part of impedance. Available orders of columns are:

nth Column	(n+1) th Col		(n+2) th Column
Frequency(f) or Angular Frequency(w)	Real(Z')	&	Imaginary(Z") part of Impedance
	Mod.(|Z|)		Phase of Impedance
	Real(Y')		Imaginary(Y") part of Admittance
	Mod.(|Y|)		Phase of Admittance

These columns should be delimited by delimiters such as space or tab.
If you attempt to open ASCII file or 3rd party's data file without a license code, the following message box will appear.

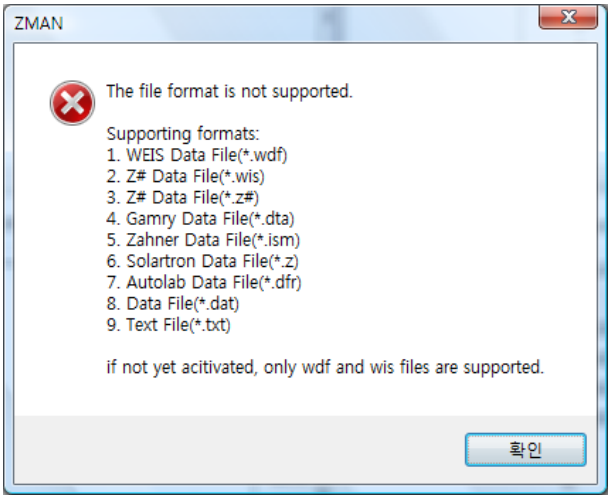


Figure 27. File format information

Once you select an ASCII format data file or after you checked the "Show dialog" check box ON, you may see the following window.

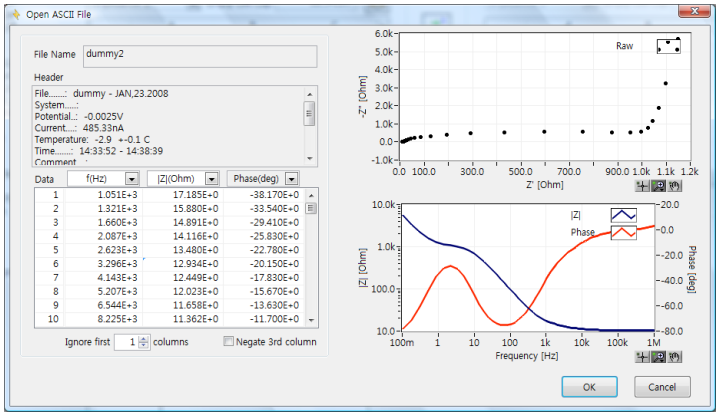


Figure 28. Read Text File

If the data file which you selected has no EIS data or invalid file format, the following message box will appear.

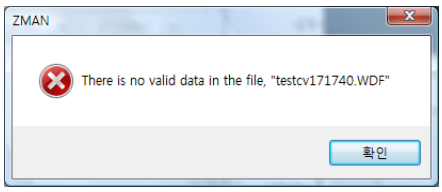


Figure 29. No data in file message

If additional columns are inserted before the three successive data columns, type the number of additional cols in the Ignore the first cols check box. With predetermined file formats, column skip function and negative colum3 selection will be inactive.

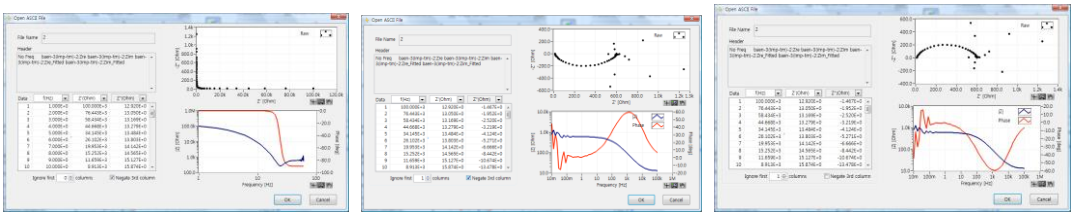


Figure 30. 1st column: serial number, Zimg polarity opposite

Sometimes, the sign convention of the third column may be inverted. In such a case, press **Negate COL3** and plot it in Nyquist Plot and Bode Diagram. With predetermined file format, column skip function and negative column3 selection will be inactive

Press "**OK"**.

Chapter 4 Preview Data file

If you selected a data file, the data file will move to preview section(B) or project section(C) when you selected project file.

A. Preview

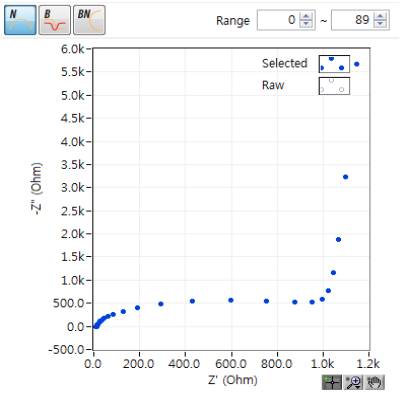


Figure 31. Preview EIS data in section "B"

When you open the data file, EIS data will be displayed in the preview section. You can check and review the data by viewing various graphic displays or data lists. You can also edit the data file before EIS data analysis.

B. Preview Data table

10. Data format

The following data formats are available for display.

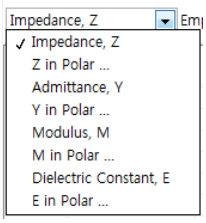
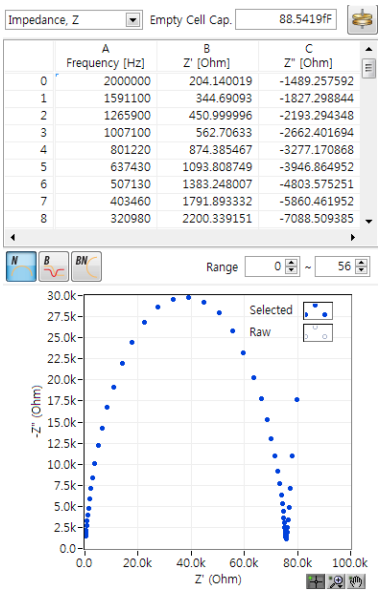


Figure 32. Data format

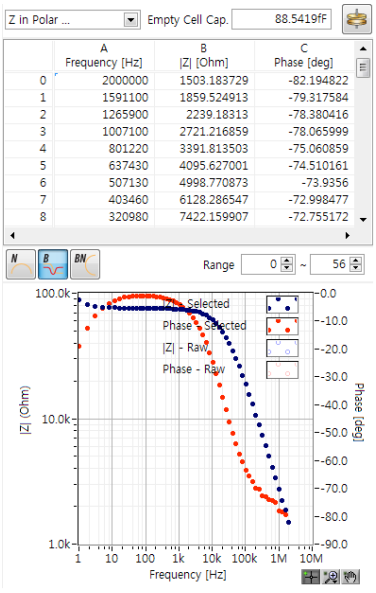
"in Polar…" means in polar coordinate.

a) Impedance Z



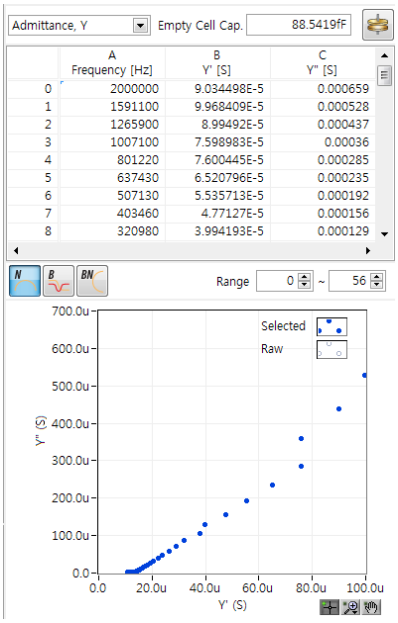
	A Frequency [Hz]	B Z' [Ohm]	C Z'' [Ohm]
0	2000000	204.140019	-1489.257592
1	1591100	344.69093	-1827.298844
2	1265900	450.999996	-2193.294348
3	1007100	562.70633	-2662.401694
4	801220	874.385467	-3277.170868
5	637430	1093.808749	-3946.864952
6	507130	1383.248007	-4803.575251
7	403460	1791.893332	-5860.461952
8	320980	2200.339151	-7088.509385

b) Impedance Z in polar



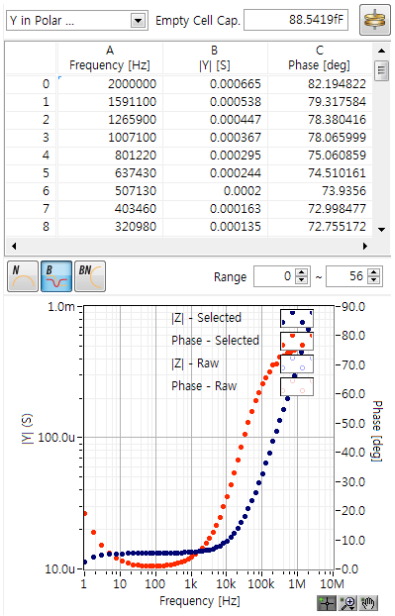
	A Frequency [Hz]	B |Z| [Ohm]	C Phase [deg]
0	2000000	1503.183729	-82.194822
1	1591100	1859.524913	-79.317584
2	1265900	2239.18313	-78.380416
3	1007100	2721.216859	-78.065999
4	801220	3391.813503	-75.060859
5	637430	4095.627001	-74.510161
6	507130	4998.770873	-73.9356
7	403460	6128.286547	-72.998477
8	320980	7422.159907	-72.755172

c) Admittance Y



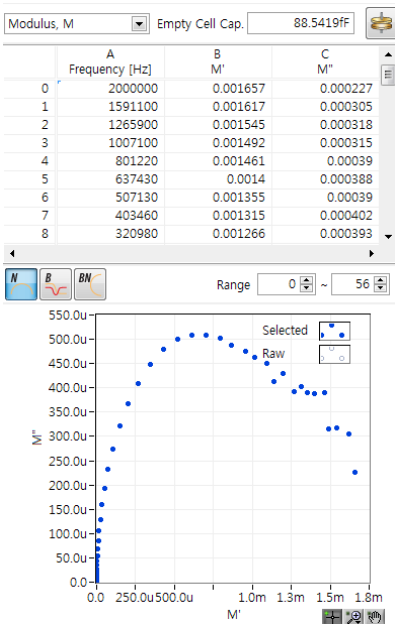
	A Frequency [Hz]	B Y' [S]	C Y'' [S]
0	2000000	9.034498E-5	0.000659
1	1591100	9.968409E-5	0.000528
2	1265900	8.99492E-5	0.000437
3	1007100	7.598983E-5	0.00036
4	801220	7.600445E-5	0.000285
5	637430	6.520796E-5	0.000235
6	507130	5.535713E-5	0.000192
7	403460	4.77127E-5	0.000156
8	320980	3.994193E-5	0.000129

d) Admitance Y in polar

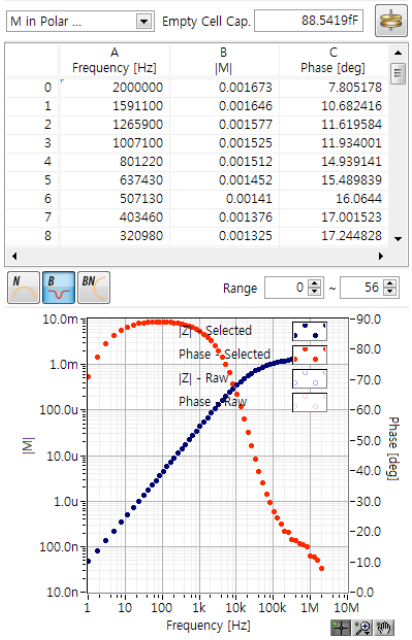


	A Frequency [Hz]	B |Y| [S]	C Phase [deg]
0	2000000	0.000665	82.194822
1	1591100	0.000538	79.317584
2	1265900	0.000447	78.380416
3	1007100	0.000367	78.065999
4	801220	0.000295	75.060859
5	637430	0.000244	74.510161
6	507130	0.0002	73.9356
7	403460	0.000163	72.998477
8	320980	0.000135	72.755172

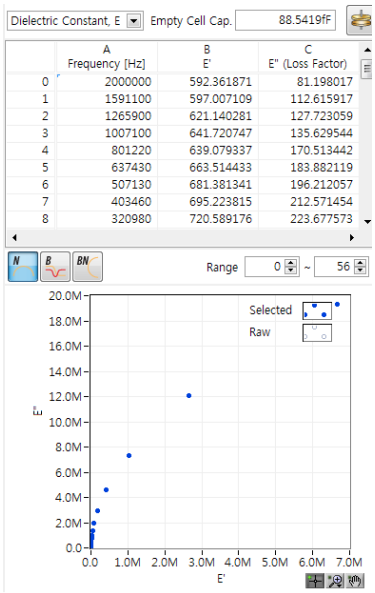
e)Modulus M



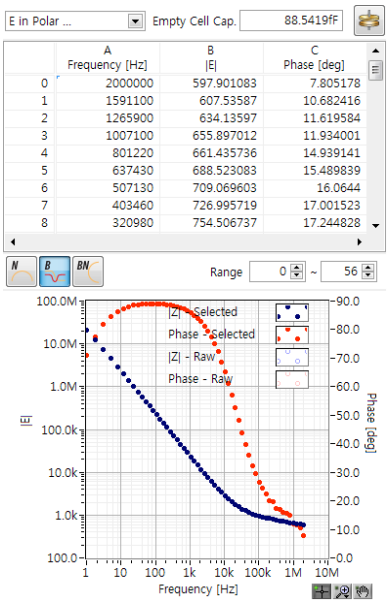
f) Modulus M in polar



g)Dielectric constant E



h) Dielectric constant E in polar



11. Empty cell capacitance value

To get dielectric constant and modulus, you must input an empty cell capacitance value

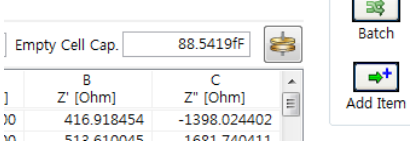


Figure 33. Empty cell capacitance value input

If you do not know empty cell capacitance value, click  button located on the input area to view the "set geometry" menu.

Click this button then you can see the following menu

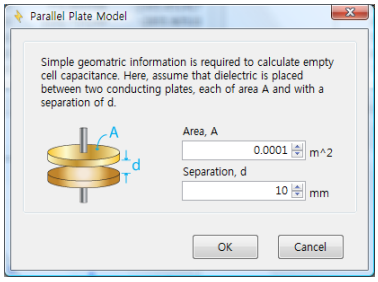


Figure 34. Parallel plate model parameter input

Area is electrode area(Unit is m^2)
Separation is the distance between two electrode (Unit is mm). If you input the two parameter value and click "OK" then the calculated empty cell capacitance will be displayed.

12. Table Menu

To see table menu, click right button of the mouse then menu will appear.

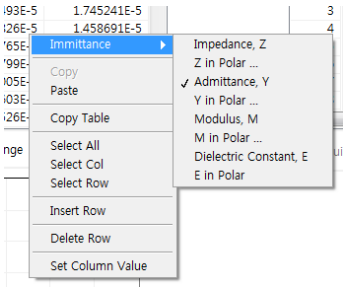


Figure 35. Table menu

a) Copy

If you want to copy row or column of table, click title or index number or "select Col" or "Select Row" and select "copy".

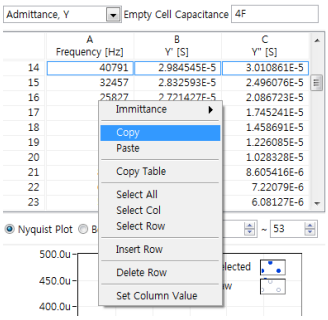


Figure 36. Row copy

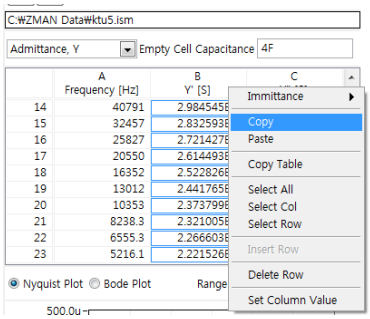


Figure 37. Column copy

b) Paste (Needs License Code)

This function is to paste the copied valued on the table. If you do not have license code, this will be inactive.

c) Copy Table

This command will copy entire table value.

d) Insert Row

This will insert a new row above the current row. This can generate new virtual data points if required.

e) Delete Row

This will delete a data point.

f) Set Column Value

You can change the value of the user defined formula. Click/select the column in which you want to change the data value and click right button of mouse to see the menu.

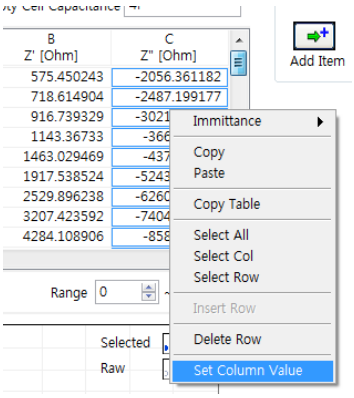


Figure 38. Set column value

The "set column value" menu will appear

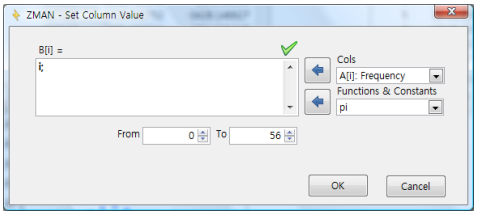


Figure 39. Set column value

If you want to change the polarity of column C (Z”), type C[i]*(-1);

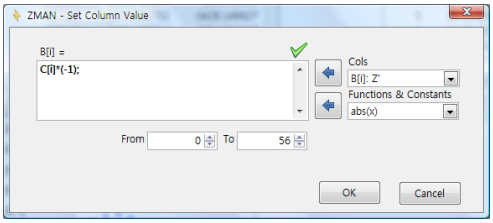


Figure 40. Input formula directly

If you click OK button column C data’s polarity will be changed.

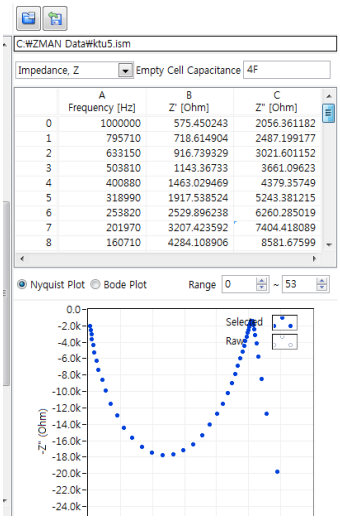


Figure 41. Polarity changed data

If you want use a predefined function, Use the following rule.

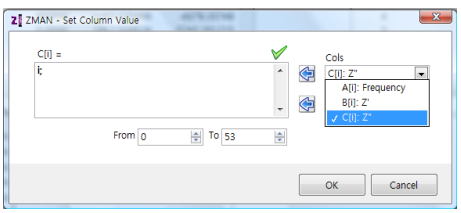


Figure 42. Select column parameter

Select column parameter which you will change with the selected function.

Click 

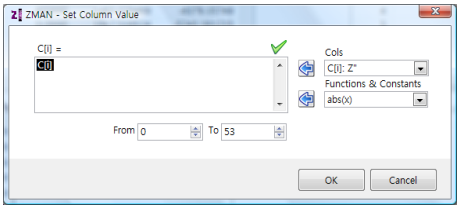


Figure 43. Dragging variable for usage of functions.

If you want to use the abs(x) function, double click or drag the parameter which you want to apply.

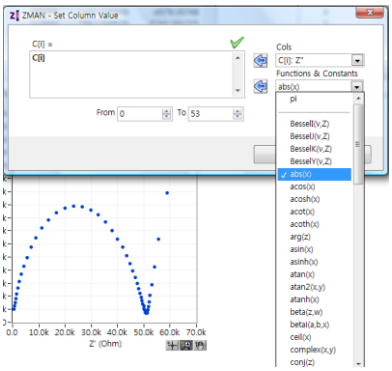


Figure 44. Select function

Select a function or constant and click 

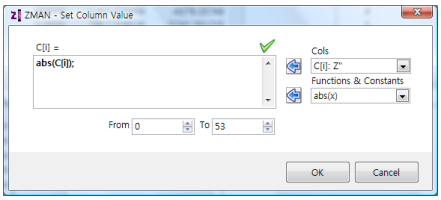


Figure 45. Set colum value result

Click OK button and the data will be recalculated.

C. Data Editing

If you want to modify the original data before analyzing, you can do it as follows.

13. Data region for analysis

You can use part of data for analysis.

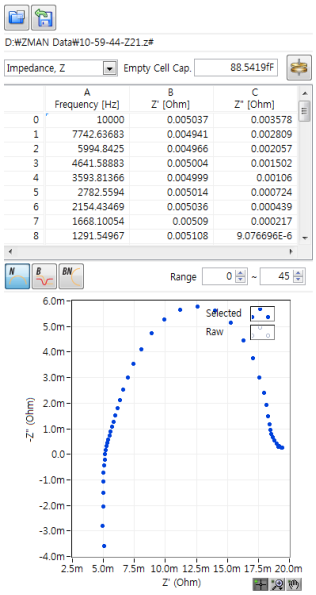


Figure 46. Preview

If you want to use positive data for Zimg, then zoom up the 0 point of Zimg by selecting regional zoom function and dragging the mouse in the area to zoom up.

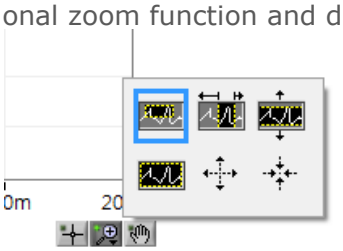


Figure 47. Zoom menu

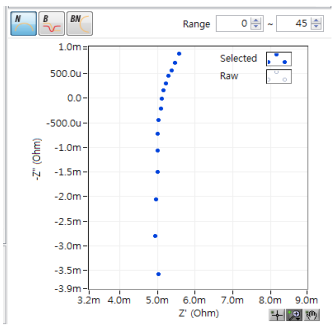


Figure 48. Zoom up

Place the mouse cursor on the graph and click right button of mouse then you can see the sub menu. Select the cursor as follows

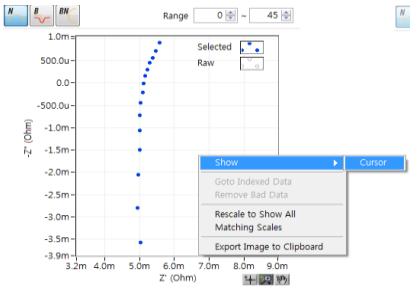


Figure 49. Cursor mode selection

You can select data point near the 0 value of Zimg by dragging the cross hair cursor and click right button of mouse.

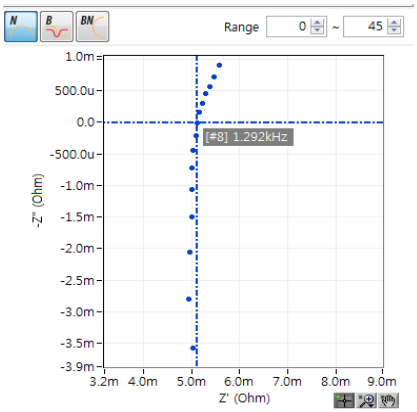


Figure 50. Select data point by cursor mode

or click right button of mouse. Then click "Goto indexed data"

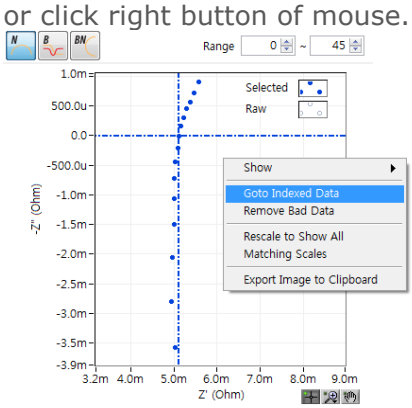
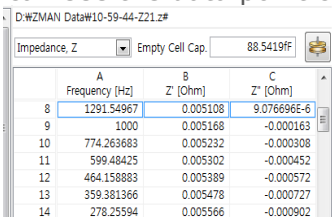


Figure 51. Cursor function

You can see the data point corresponding to the cursor location.



	A Frequency [Hz]	B Z' [Ohm]	C Z'' [Ohm]
8	1291.54967	0.005108	9.076696E-6
9	1000	0.005168	-0.000163
10	774.263683	0.005232	-0.000308
11	599.48425	0.005302	-0.000452
12	464.158883	0.005389	-0.000572
13	359.381366	0.005478	-0.000727
14	278.25594	0.005566	-0.000902

Figure 52. Cursor pointed data

The cursor pointed is the 8th data point in data list. You can input 8 in the Range box instead of 0.

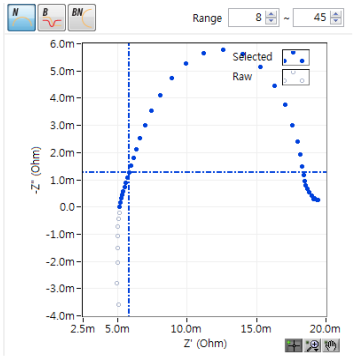


Figure 53. Selected data region

Selected data will be displayed in blue. These data points will be used for analysis.

Click the 

icon and the selected data set will be transferred to project section"C"

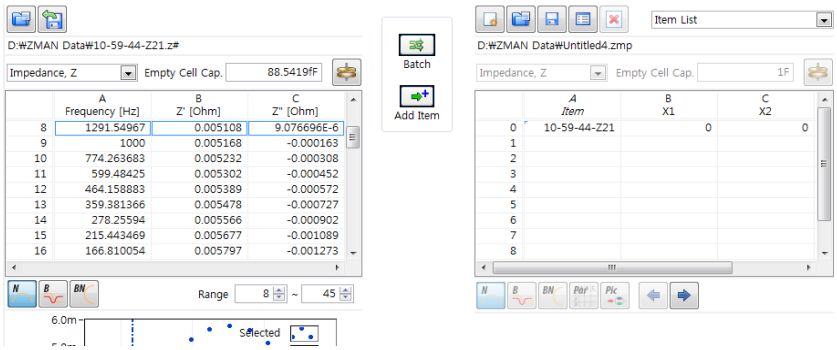


Figure 54. Transferring data set to project

You can preview the data by selecting file name at section "C"

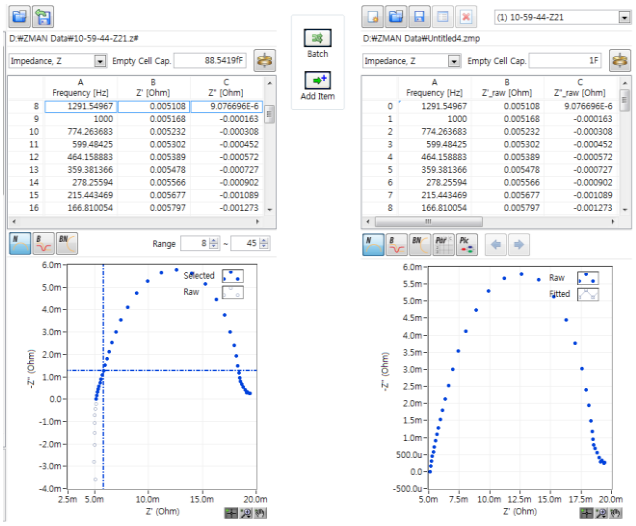


Figure 55. Data preview in project

14. Delete Data points

If you want to edit "bad" data point(s) on original data before analysis, you can do it using the following process.

To find bad data, zoom up by selecting the regional zoom function and dragging the mouse on an area to zoom up.

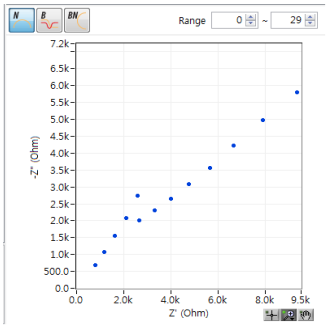


Figure 56. Zoom up

By cursor function, move the cross-hair cursor to the bad data.

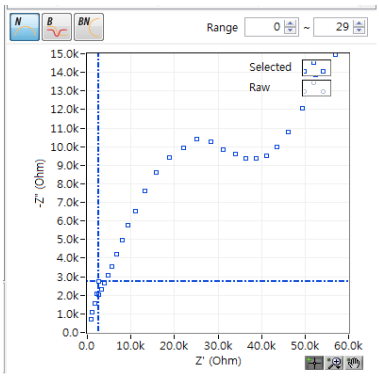


Figure 57. Cross hair cursor on bad data

Click right button on graph and select "Remove bad data"

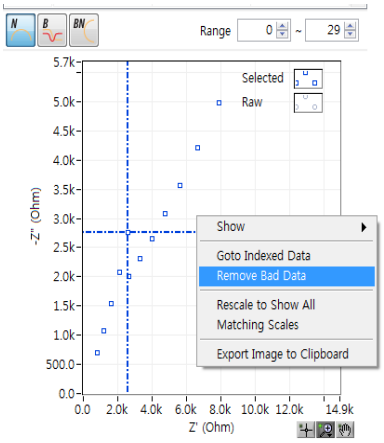


Figure 58. Remove bad data

..and the bad data point is removed.

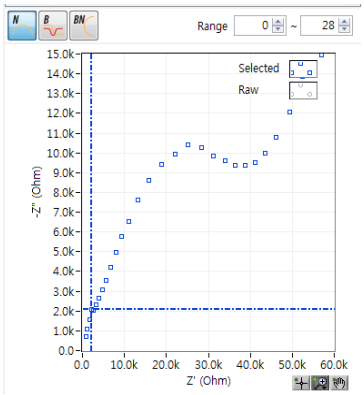


Figure 59. Bad data deleted

15. Extrapolating Bad data

If you want to edit data using extrapolation, you must first change to a Bode graph format.

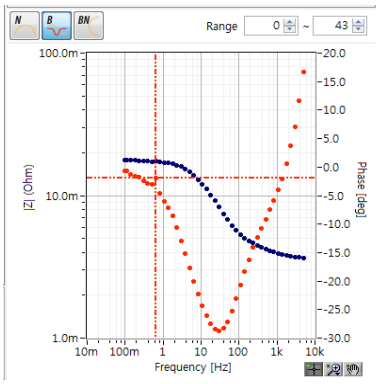


Figure 60. One point bad data on Bode plot

You can select bad data by cursor function and click right button of mouse. Then click interpolate bad data.

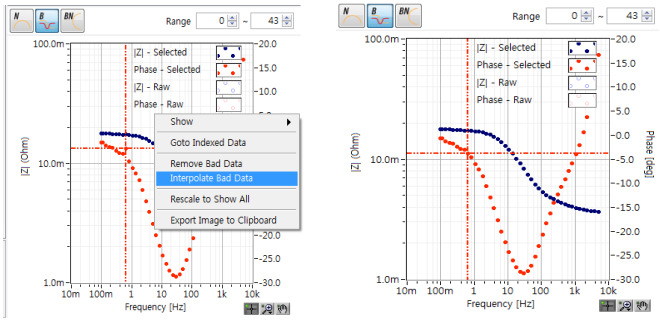


Figure 1. Interpolate bad data(before & after)

16. Editing Data points

If your data contains bad data points, you can change the point value.

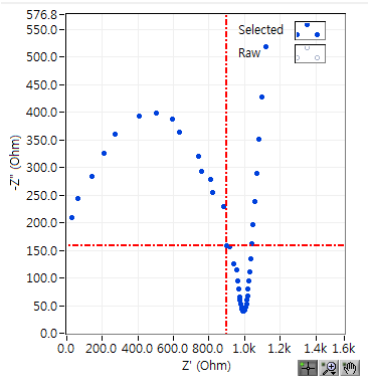


Figure 61. Select bad data by cursor function

You can select bad data by cursor function and click right button of mouse. Then click "Go to indexed data".

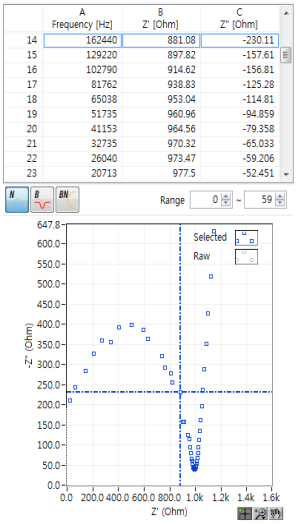


Figure 62. Bad data value list

You can change the value of Zimg to -180.

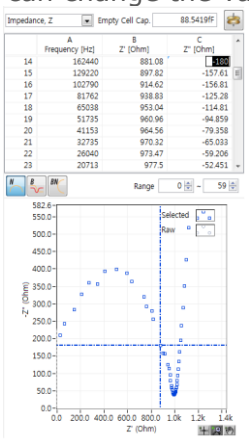


Figure 63. Edit bad point

You can delete or modify the bad data points in project section.

D. Preview graph Menu

17. Nyquist Plot

To display a Nyquist plot, click  button. To view pop up menu, click right button on plot region.

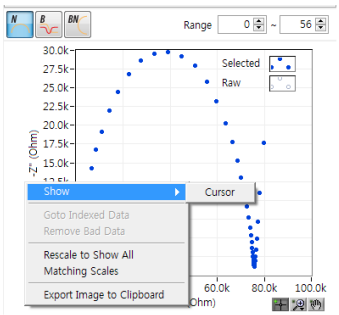


Figure 64. Nyquist pot

a) Cursor

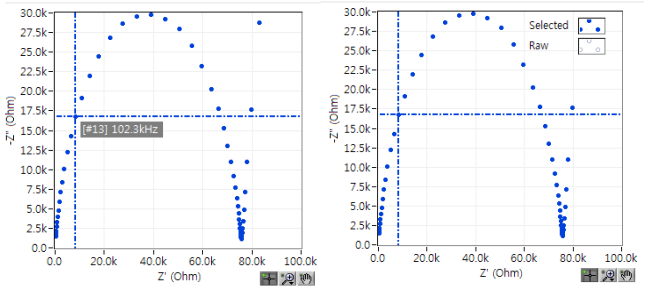


Figure 65. Nyquist plot cursor display

If you move mouse cursor to cross hair and click on it then you can see the point information as the left side graph (point number and frequency) If you release the mouse button, you can see the right side graph.

At cursor mode, pop up menu is as the follows.

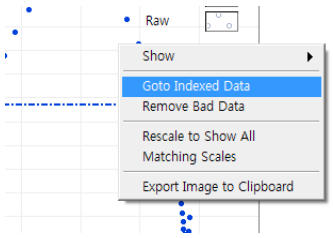


Figure 66. Pop up menu on Nyquist plot

Goto Indexed Data & Remove Bad Data is activated.

b) Legend submenu

You can only move the mouse cursor onto Legend when the pop up menu is displayed, then click right button of mouse.

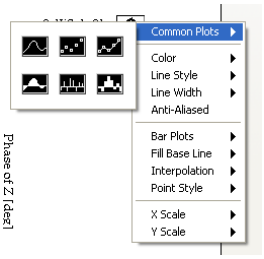


Figure 67. Legend submenu

You can change each line's properties using this pop up menu.
You can refer to this function in the Graph section.

c) Remove Bad data

You can delete cursor pointed data.

d) Rescale to show all

If the graph was zoomed up, it will auto scale to display the whole graph

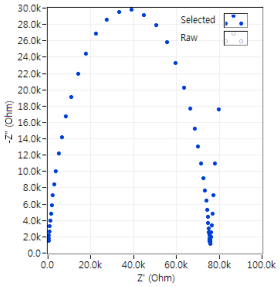


Figure 68. Rescale to show all in Nyquist

e) Matching scale

This will display X axis scale equally to Y axis scale.

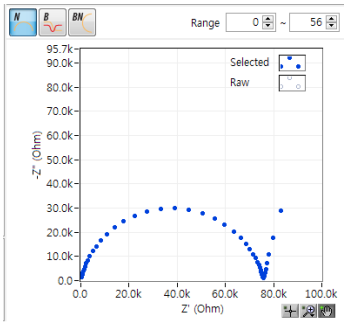


Figure 69. Matching scale in Nyquist

f) Export image to clipboard

Copy graphic into clipboard to use in other application software such as Word, Excel etc.

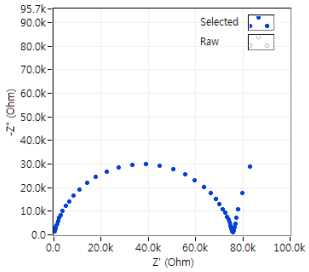


Figure 70. Clipboard image

18. Bode Plot

To display data as a Bode plot, click  button. To view pop up menu, click right button on plot region. Same as Nyquist plot above except for appropriate matching scales.

a) Cursor

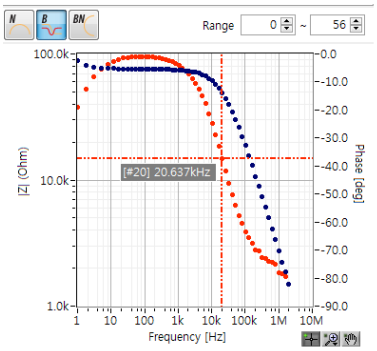


Figure 71. Bode Plot cursor display

Same function as with Nyquist plot. Pop up menu on cursor mode is as the following.

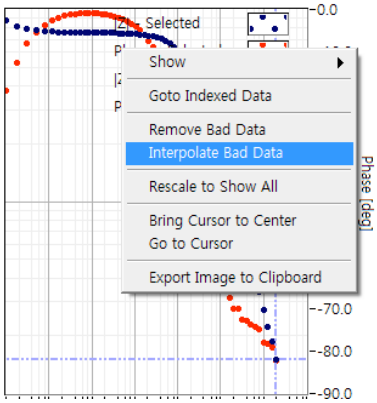


Figure 72. Pop up menu on Bode plot

Same function as with Nyquist plot except Interpolate bad data function.

b) Legend submenu

You can only move the mouse cursor onto Legend when the pop up menu is displayed, then click right button of mouse.

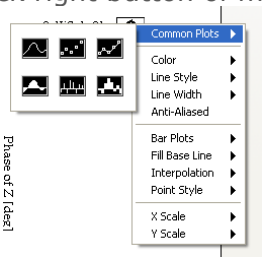


Figure 73. Legend submenu

You can change each line's properties using this pop up menu. You can refer to this function in Graph section.

c) Remove Bad data

Cursor selected data can be deleted.

d) Interpolate Bad data

With this function, ZMAN will replace a cursor selected point with a point interpolated between two adjacent points.

e) Rescale to show all

If the graph was zoomed up, this function will autoscale scale to display the whole graph

f) Export image to clipboard

Copy graphic into clipboard to use in other application software such as Word, Excel etc.

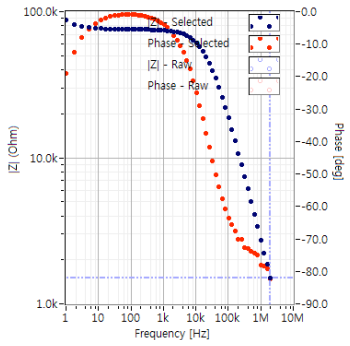


Figure 74. Clipboard image

Chapter 5 Project

A. How to Use the Project ("C" section)

ZMAN software was designed to handle impedance data file using a project concept. The Project can contain several EIS data files that can be used for the analysis of serial measurement files or grouped data files. This approach can manage data files related by some control variables.
For example, for the evaluation of properties of a battery, one may measure impedance of the battery in its open circuit state. In such a case control variable is OCV. These data files sets can be saved as a project file together with analysis result.

If you have already opened a project file (*.zmp), ZMAN automatically loads it in the Project section"C".

B. Data file transfer to project

You can upload multiple files to a project by the process described below.

19. Add item

You can transfer data file on preview section to the project section by clicking "Add item" button.

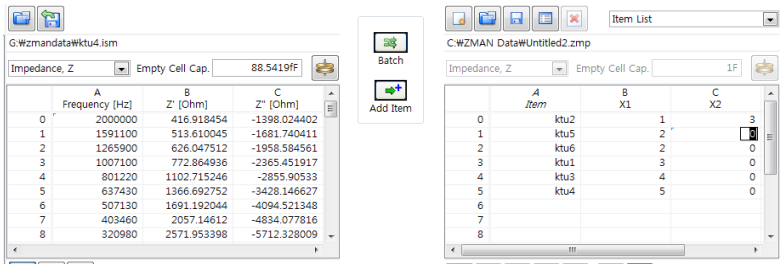


Figure 75. Upload EIS data file

20. Batch transfer

You can transfer multiple data files to the project section by clicking "batch" button or select batch on file menu (short key: ctrl + B). When you click "batch" button, you can select multiple data files. If these files need text file importing function, these will be performed sequentially.

21. Merge

You can merge other project files into current project without clearing the project. This function can be done by selecting Merge in File menu. If you select other project file directly, current project will be cleared.

22. File part transfer to project

If your data file contain cyclic impedance data then you can break down each impedance measurement cycle using data region transfers.

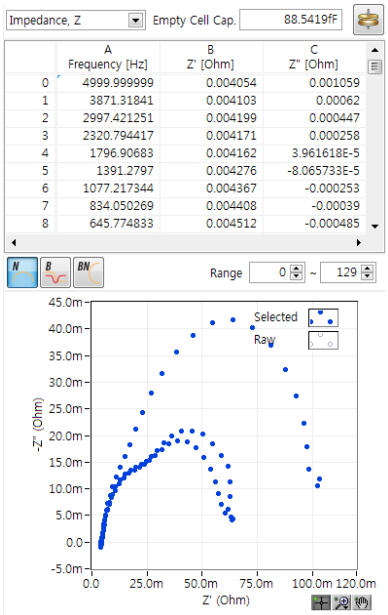


Figure 76. Data file containing multiple EIS data set

You can check how many data points included in one EIS data set on data list. And input each data set's range.

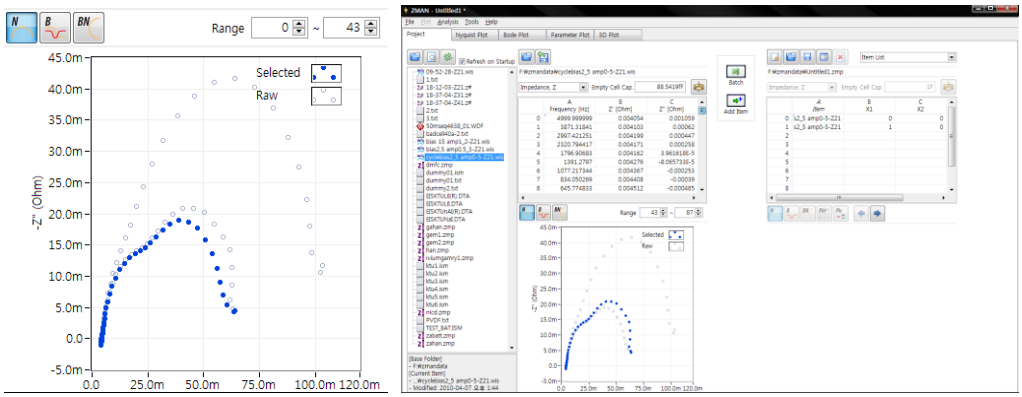


Figure 77. Data transfer by splitting.

You can transfer each data set to project as a separate file.

C. External parameter setting

If you have uploaded multiple files, you can you can input values, at X1, X2, X3, such as temperature value, voltage value, distance value etc. for use in a parameter plot. To input a value, double click on the required cell and input the value as shown in Fig 78.

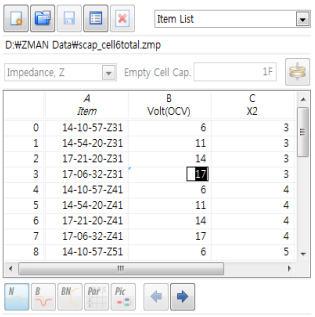


Figure 78. Parameter editing

Also you can define (name) parameters (X1, X2, and X3) by clicking "Edit item" icon  in "C" section

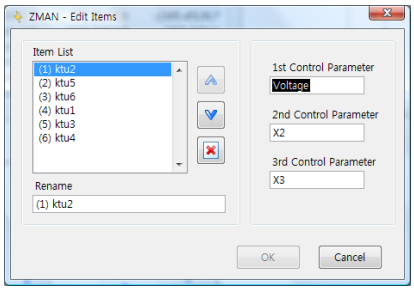


Figure 79. Labeling Control Parameters

If you change parameter name, these name will be used for parameter plot or 3D plot. You can upload multiple data files by clicking "Batch" button at central part. You can upload multiple data files by clicking "Batch" button at central part. You can select multiple files by normal windows ctrl/ shift button operation.

Note: Batch uploading will not display preview (section "C").

D. Data file order change

For series fitting and data display in 3D plot, you need file order adjustment.
If you want to change the order of files of the list, Select one file name in the item list and click up or down icon to move to wanted location.

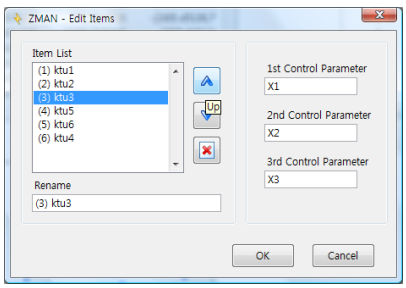


Figure 80. Edit item

E. Open data file directly

23. Project file reading

You can open the project file(file extension: zmp) by clicking folder icon  at "C" section or double click project file at file browser (section "A")
In this case current folder's data will be cleared.

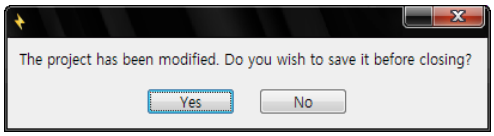


Figure 81. Warning message

24. WDF file reading

If your WDF file(WEIS data file) has multiple impedance data set by cycling, it can be directly transfer set of data to project region(section"C"). When you did double click on WDF then following message box will appear.

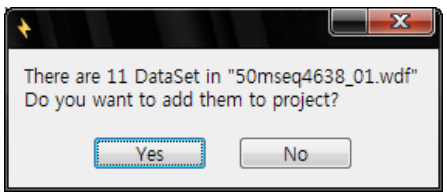


Figure 82. Multiple data set WDF file opening

If you click Yes button, all set of data will transfer to project.
These files will be added to current project file configuration.

F. Data preview on Project

If you want to preview data files in a project, click index number for the data file name on item list or select file name on combo box. Data preview function is same as in Preview section. You can refer to chapter 4 Preview data file.

25. File selection to preview

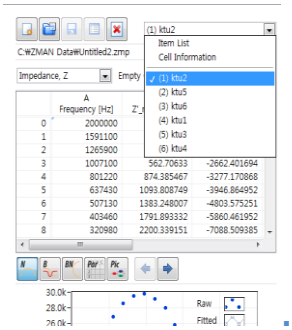


Figure 83. Select file name on combo box

Or double click the index number on item list.

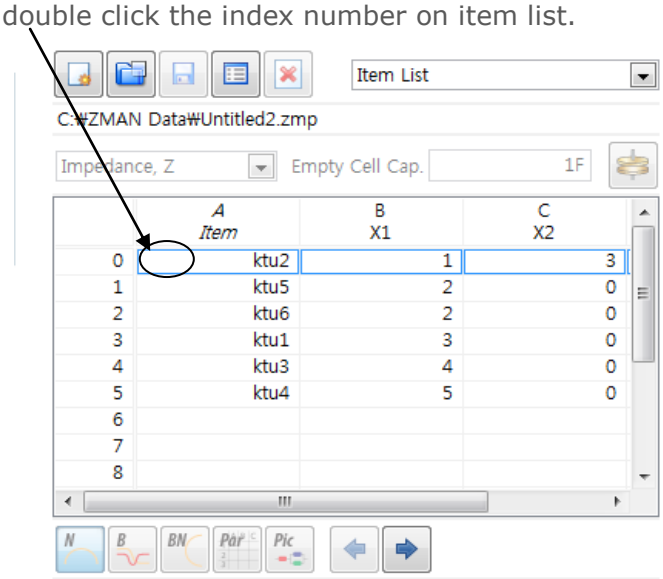


Figure 84. Select file name on item list

Then you can see preview for the data file as Nyquis, Bode, Black Nichols, Parameter value and model pictorial with data list

You can also change the preview file using arrow key 

26. Preview type selection

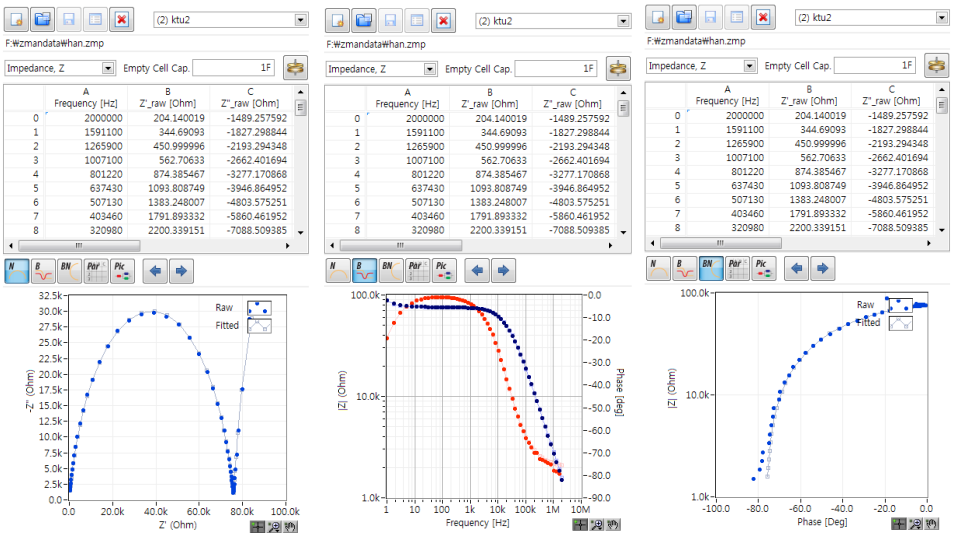


Figure 85. Preview graphics on Project (Nyquist,Bode,Black Nichols plot)

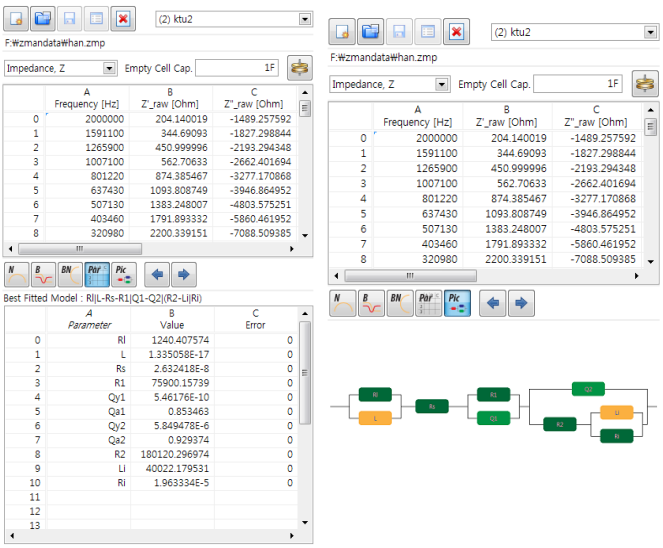


Figure 86. Preview parameter info & model pictorial

G. Data Editing on Project

You can delete or modify the bad data in the project section. Refer to Preview section regarding to data editing.

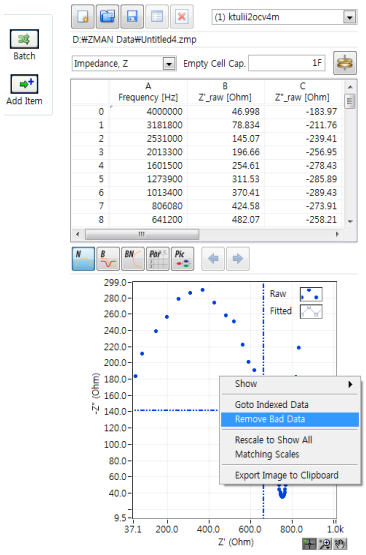


Figure 87. Data editing on project

Chapter 6 Data analysis

A. Kramers-Kronig Consistency

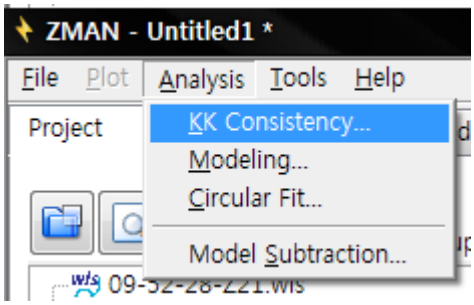


Figure 88. KK Consistency menu

27. Kramers-Kronig relation

The validity of Complex Impedance data may be checked by the Kramers-Kronig Relation. The Kramers-Kronig Relation is given by the following.

Z″ to Z′ Transform:

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

Z′ to Z″ Transform:

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

In order to perform the calculation, ZMAN first interpolates impedance data with points equally spaced in the frequency domain. After that, the interpolated data is calculated by Maclaurin's series method.

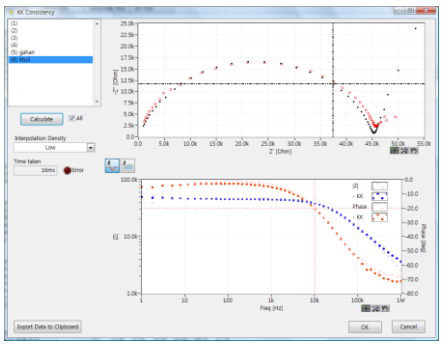


Figure 89. KK consistency

28. Data File Selection

Select a data file to be analyzed in the Filenames Box. If you want to analyze all data in the project, tick "All" check box.

29. Interpolation Density option

Select an option in the "Interpolation Density" list box. There are three options: Low, Medium, and High. If you select High, it may take around half minute to complete the calculation, depending on the performance of your computer.

30. Calculate

Click Calculate. After calculation if there is error, error color will change to red. Calculation time will be displayed.

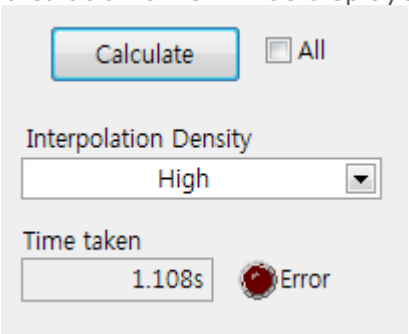


Figure 90. Calculated result

31. Graph

There are Nyquist plot and Bode plot to show KK consistency result.
To view pop up menu for graph, click right mouse on graph region.

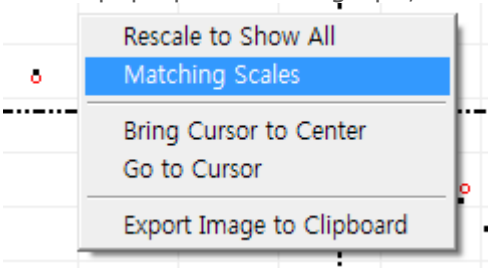


Figure 91. Nyquist plot pop up menu

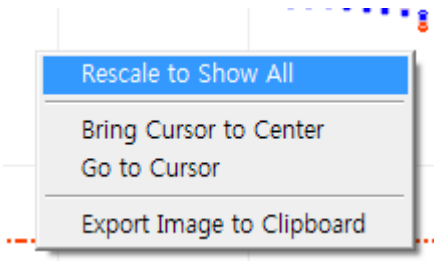


Figure 92. Bode plot pop up menu

32. Check Validity

After completion of the calculation, you may check the validity of your impedance data by comparing data and result in the Nyquist Plot and Bode Diagram. The difference between both is shown in the Error Graph, where ΔZ and ΔPhase is calculated by the following equations:

$$\Delta Z\,[dB] = -20\log\left[\frac{Z_{KK}}{Z_{raw}}\right] \quad \textbf{and} \quad \Delta Phase\,[\deg] = \varphi(Z_{KK}) - \varphi(Z_{raw})$$

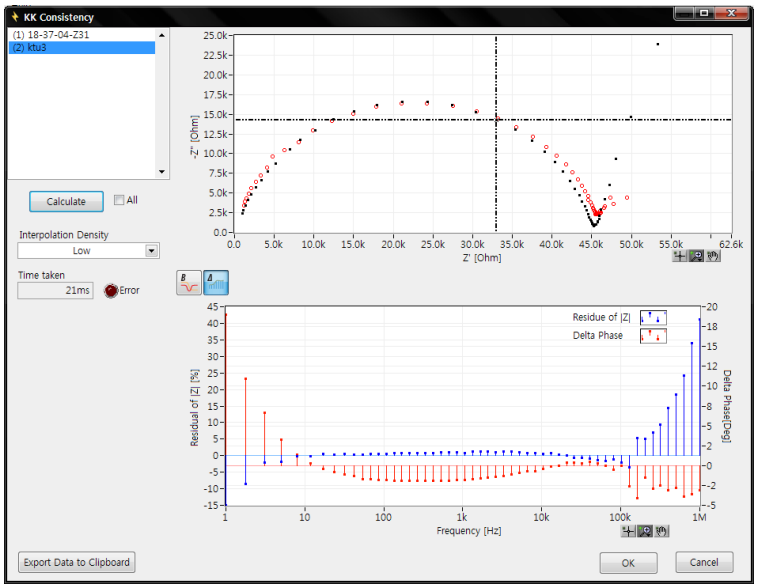


Figure 93. KK consistency error diagram

33. Import data to clipboard

When you click "import data to clipboard" button, KK consistency calulation result will be copied to clipboard.

No	Freq	(1) ktu3:Zre	(1) ktu3:Zim	(1) ktu3:Zre_KK	(1) ktu3:Zim_KK
1	1.000000E+6	9.534747E+2	-2.402724E+3	1.161808E+3	-3.456998E+3
2	7.957100E+5	1.140401E+3	-2.837647E+3	1.282861E+3	-3.891953E+3
3	6.331500E+5	1.425871E+3	-3.414924E+3	1.480751E+3	-4.350381E+3
4	5.038100E+5	1.712020E+3	-4.079632E+3	1.790460E+3	-4.928293E+3
5	4.008800E+5	2.131309E+3	-4.828724E+3	2.129337E+3	-5.645927E+3

When you click OK button, KK consistency result will be applied on project. If you click "Cancel" button, result will be discarded

B. Modeling

In order to fit your EIS data to an equivalent circuit, Enter to Modeling Menu..

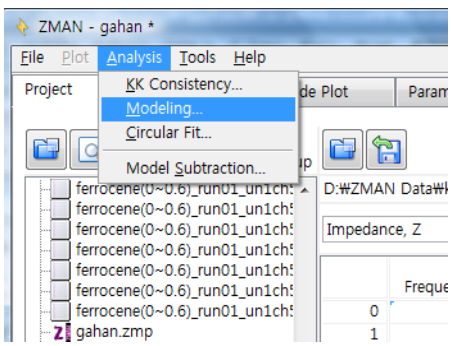


Figure 94. Modeling menu selection

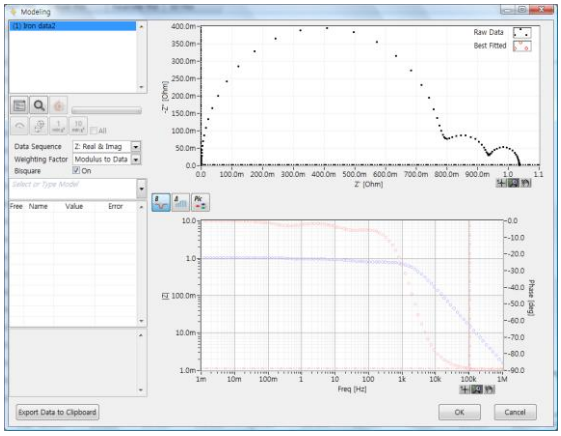


Figure 95. Modeling

34. Select data

If your project has multiple EIS data sets, select the data that you want to fit from the left-upper list box.

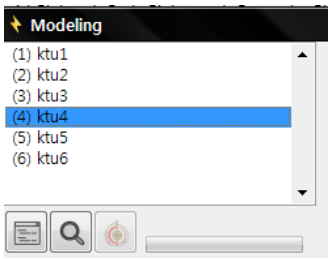


Figure 96. Data selection

35. Search Model

When you are uncertain as to which model best fits the data, click  search model button. You can quickly and easily search available models that best fit the data.
See ”Automatic Model Search” Search Suitable Equivalent Circuits for details. This step may be skipped.

36. Select Model

You can select model directly from model editor or by input equivalent circuit symbol.

a) From Model editor

Click  Select Model button in order to select an equivalent circuit to be applied to the data. See “**Equivalent Circuit Model editor**” for details.
You can select model in model library. Each library has same model with different initial parameter values. If you selected one model in equivalent circuit model editor by clicking 

button, its initial value in the model will transferred to Modeling window.

b) Direct Input Model symbol

You can input Symbol in model input box as same rule in model editor.

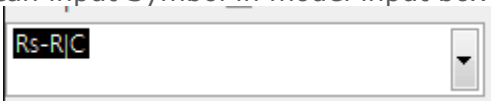


Figure 97. Symbol input box

If you did not complete it, following error message will appear.

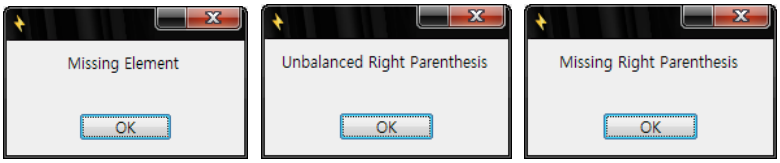


Figure 98. Error message box

See "**Equivalent Circuit Model editor**" for details

c) Select Model in combo box.

You can select model list on combo box. The listed models are from libraries.

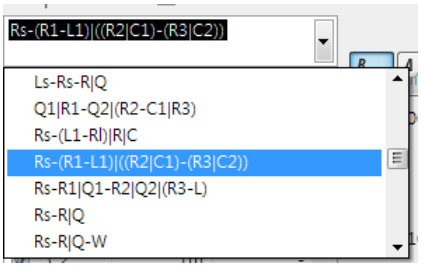


Figure 99. Model selecting combo box

37. Data sequence and Weight

Select a data sequence and a weighting method.

a) Data sequence

You can select data set which will be used to fit.

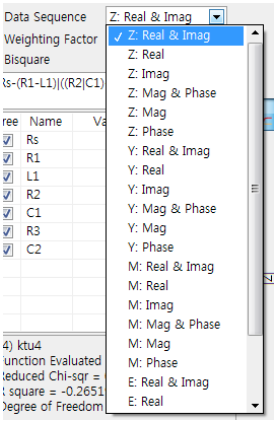


Figure 100. Data sequence selecting

Default data set is Zreal and Zimg for Nyquist plot
You can change other data set following data characteristics to get more accurate fitting result.

b) Weighting Factor

You can select weight factor on fitting process.
Default is modulus to data.

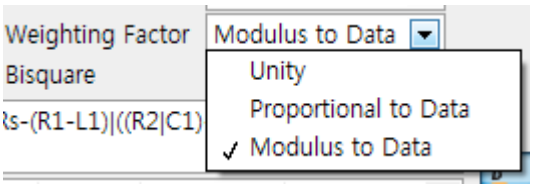
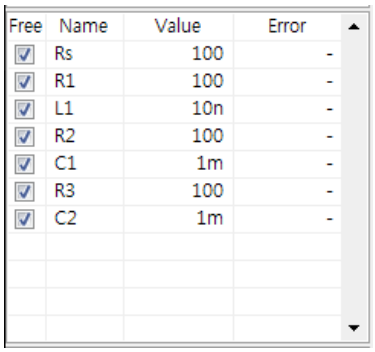


Figure 101. Weighting factor

38. Model Parameters



Free	Name	Value	Error
☑	Rs	100	-
☑	R1	100	-
☑	L1	10n	-
☑	R2	100	-
☑	C1	1m	-
☑	R3	100	-
☑	C2	1m	-

Figure 102. Model parameter window

You can modify model parameters value to use as initial values of fitting process.
When you input value, Nyquist plot and bode plot display(fitting curve) will be changed following this value.

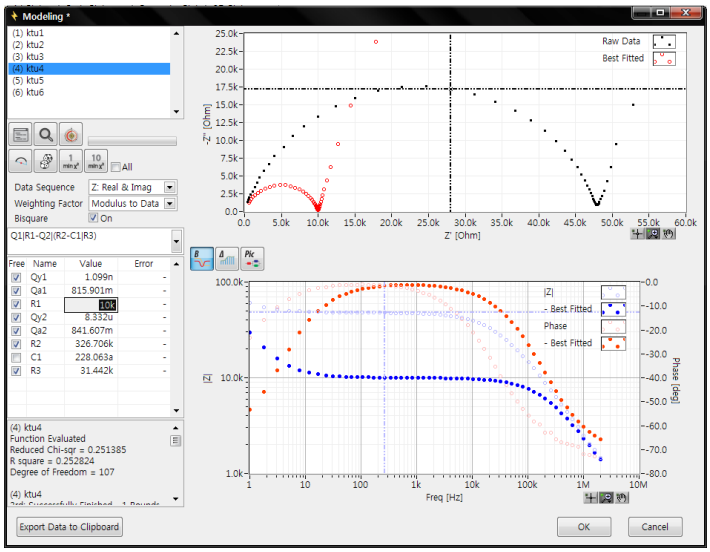


Figure 103. Parameter input result

39. Initial guessing

There are 3 initial guessing method.

a) Direct parameter value input
b) Simple circular initial guessing
c) Genetic analysis initial guessing

For details See "**Automatic Model Search**"

40. Fit Data

Click Fit Data one round minimize 

or 10 round minimize 

to fit model parameters to the model. You can do series fitting when you check on "ALL" 

. Then fitting process will done sequentially data by data. After the fitting routine is finished, you may compare the best-fitted data against raw data in Nyquist Plot and Bode Diagram. Check All TRUE to fit parameters of impedance series. ZMAN automatically use best-fitted parameters as initial values to fit the next impedance data set. So you need to locate data set in order as changing control test conditions such as time, voltage etc.
You can change file location order in project tab's **edit items**.

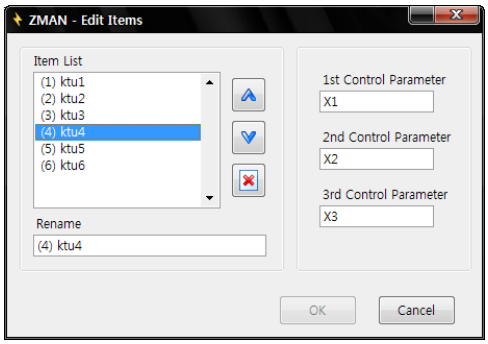


Figure 104. File location order change

Note: If you use series fitting using check on 

, Fitting process will use 1st data's model with its parameter setting in fixed or free for all other data sets even if you selected other model for other data set.

In Error Graph, ΔZ and ΔPhase is calculated by the following equations:

$$\Delta Z\,[dB] = -20\log\left[\frac{Z_{BestFitted}}{Z_{raw}}\right] \quad \text{and} \quad \Delta Phase\,[\deg] = \varphi\,Z_{BestFitted} - \varphi\,Z_{raw}.$$

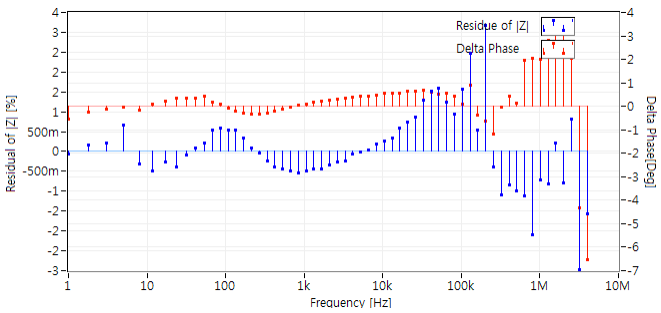


Figure 105. Error graph

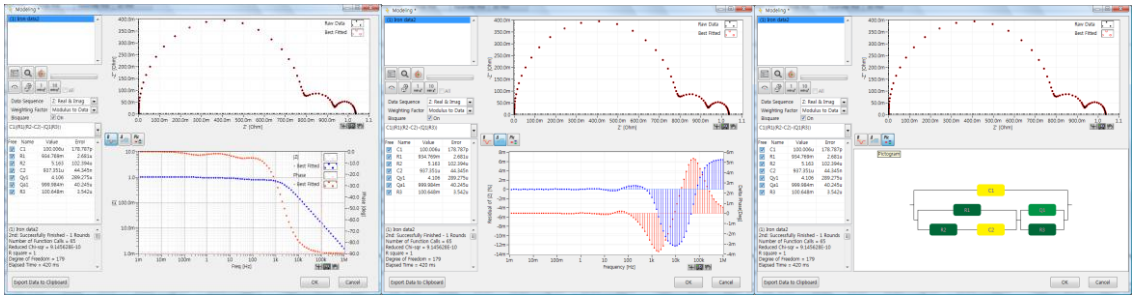


Figure 106. Model fitting result

You can view the equivalent circuit model by clicking "PIC" button.

Left bottom side information is fitting result. If you see "Singular matrix…", fix the parameter in model by checking out "Free" section and do fitting again.

41. Bisquare option

Check on Bisquare option, you will get more accurate result but it takes more time.

42. Parameter free/fix

Only free parameters will be used for fitting. If some parameter(s) are set as fixed, those parameter will not be used for fitting process. There are two free condition by fitting value range

a) Positive value acceptable only

ZMAN will fit the parameter value within positive value. If you set this one, free mark will be ☐.

b) All value including negative acceptable

ZMAN will fit the parameter value with all value. If you set this one, free mark will be ☑. If parameter was fixed free the mark will be ☐. You can set all parameter as positive value only or all parameter by cliking right mouse button on "Free" characters then following pop up menu will appear.

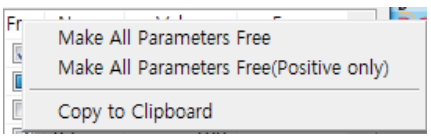


Figure 107. Free option pop up menu

You can change free status per parameter by click this mark then mark will be changed by every clicking. 

If you select copy to clipboard, each parameter's setting information will copied to clipboard as;

Free,Rs,100,-
Free(+),R1,100,-
Fixed,C1,0.001,-
Free,R2,100,-
Free,C2,0.001,-
Free,R3,100,-
Free,C3,0.001,-

43. Fitting history information

Every fitting process will be logged and displayed at left bottom side

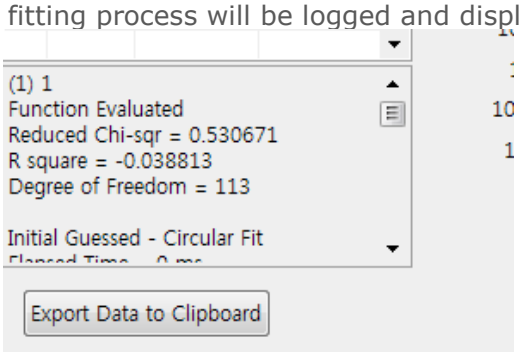


Figure 108. Fitting history information

a) Initial guessing log.

If you do initial guessing, following information will be logged.

Simple circular

(1) 1
Function Evaluated
Reduced Chi-sqr = 0.530671
R square = -0.038813
Degree of Freedom = 113

Initial Guessed - Circular Fit
Elapsed Time = 0 ms

Genetic analysis

(1) 1
Function Evaluated
Reduced Chi-sqr = 0.075619
R square = 0.963088
Degree of Freedom = 113

Initial Guessed by Genetic Analysis
Fitness(Chi-sqr) = 0.075619
Number of Populations = 100
Number of Generations = 175
Elapsed Time = 13135 ms

b) Fitting log

Successful fitting result

(1) 1
3rd: Successfully Finished - 1 Rounds
Number of Function Calls = 56
Reduced Chi-sqr = 0.000364
R square = 0.999826
Degree of Freedom = 113
Elapsed Time = 167 ms

2nd: Successfully Finished - 1 Rounds
Number of Function Calls = 45
Reduced Chi-sqr = 0.000316
R square = 0.999799
.
.

Singular Matrix result

(1) 1
Singular Matrix - Fix Qa2 - 1 Rounds
Number of Function Calls = 184
Reduced Chi-sqr = 0.000412
R square = 0.999952
Degree of Freedom = 112
Elapsed Time = 694 ms

If a singular Matrix result is produced, there will be no Error value on the result.

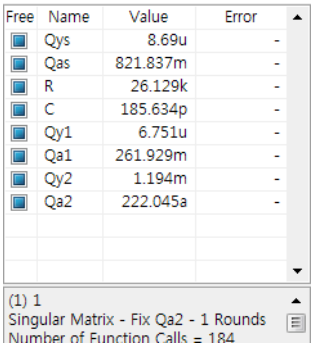


Figure 109. Singular matrix result

In this case, you must FIX ☐ by clicking off the parameter reported in the log (*Qa2*) and do fitting again.

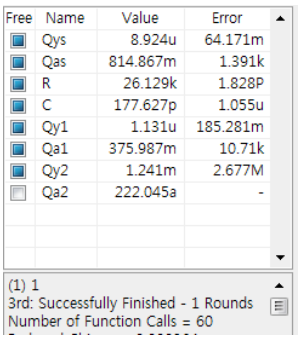
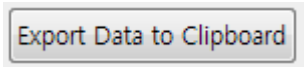


Figure 110. Fitting result after fixing parameter

44. Export Data to clipboard

Click 

to copy best-fitted parameters or data to clipboard then following message box will appear.

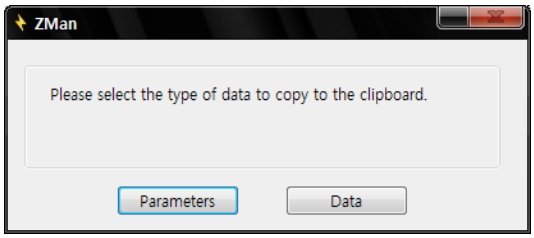


Figure 111. Fitting result clip board copy

Click Okay to close this window. If you click OK button, fitting result will be accepted and can be saved in project file. If you click Cancel button, fitting result will be discarded.

Circular fitting

If your EIS data's Nyquist plot contains circle(s), you can get circle information using this fitting function.

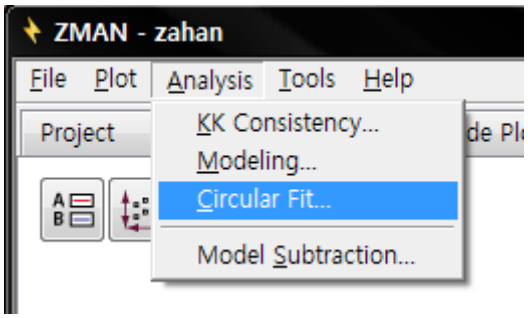


Figure 112. Circular fit menu

When you selected Circular fit function, circular fit menu will show with 1st data. ZMAN will do circular initial fitting automatically. If there are no previous analysis including circular fit, modeling, ZMAN will set data range for circular fitting that includes all data. If there was a previous analysis, data range will be changed following previous result.

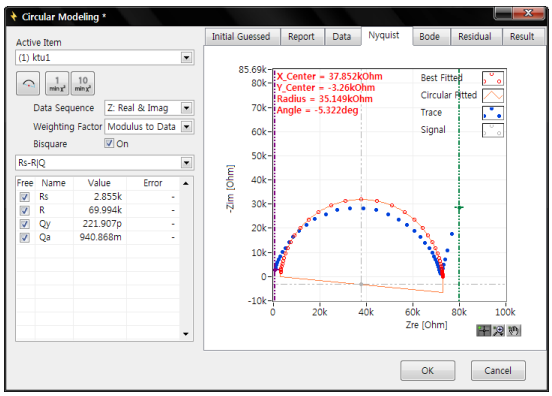


Figure 113. Circular fit menu

45. Data file selection

Select data file for circular fitting on an active item

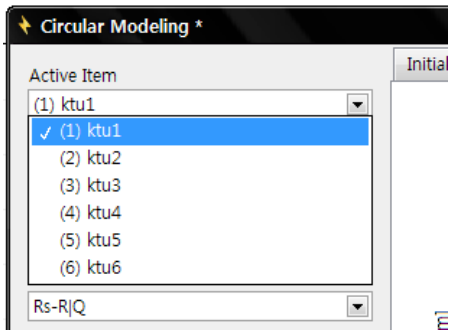


Figure 114. Data file selection

When you select new data file, ZMAN will do circular initial fitting again automatically.

46. Data range setting for circular fitting

If you did not analyse selected data before, data range will include all data.

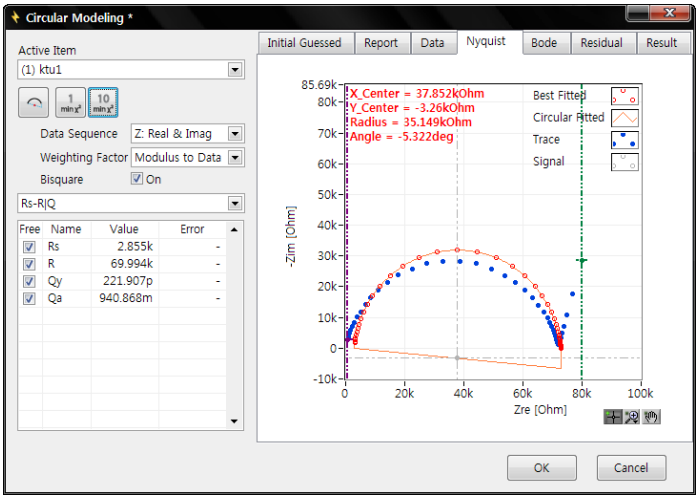


Figure 115. Before range setting

Move left(violet) & right(olive) cursor bar into circle region by clicking and dragging the cursor bar.

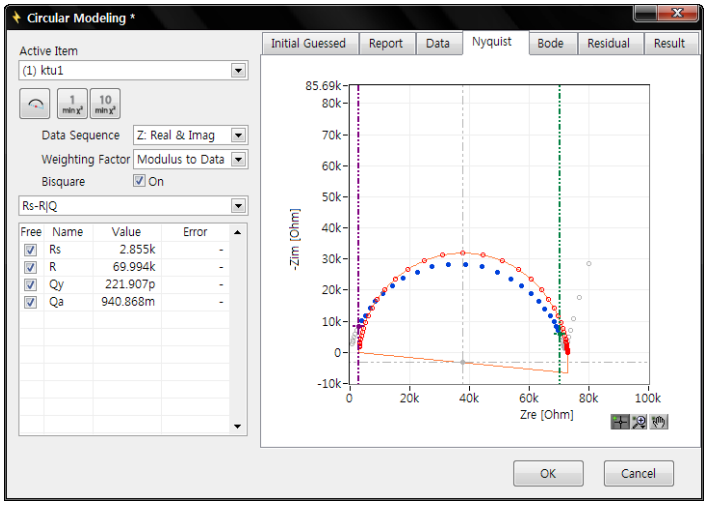


Figure 116. After range setting

Data points color outside of range bar will be change to grey. Blue colored data points will be used in calculation for circular fitting.

47. Graph pop up menu

You can display the pop up menu by clicking right mouse button in the graphic region.

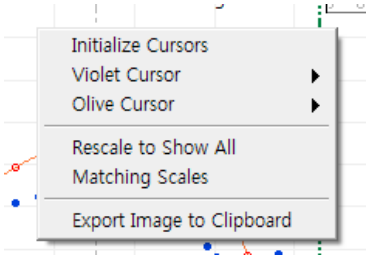


Figure 117. Graph pop up menu

a) Initialize cursors

This will relocate two cursor bar to initial position.

b) Violet cursor/Olive Cursor

Go to center: Cursor bar will locate at center
Go to cursor: Graphic window will locate at cursor

c) Rescale to show all
d) Matching scales

Adjusting Nyquist plot X, Y axis with same scale

48. Circular Initial guessing

After setting data range by moving cursor bars. If you click the circular Initial guessing icon  , then circular fitting will be done with new setting data range.

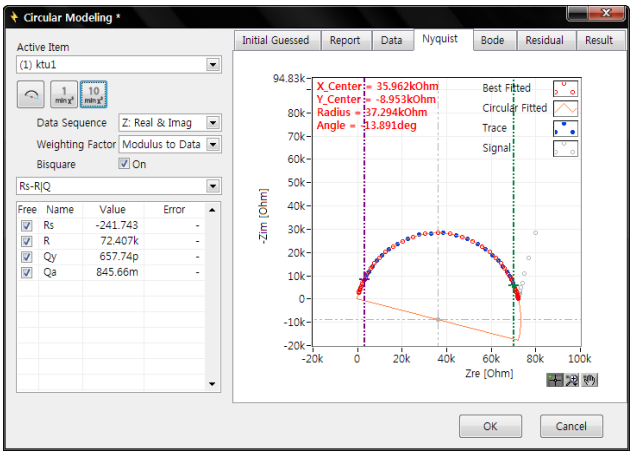


Figure 118. Circular fitting data range setting

If there are multiple circles and you want to fit other circle, move cursor bar to the circle region and click the guessing icon.

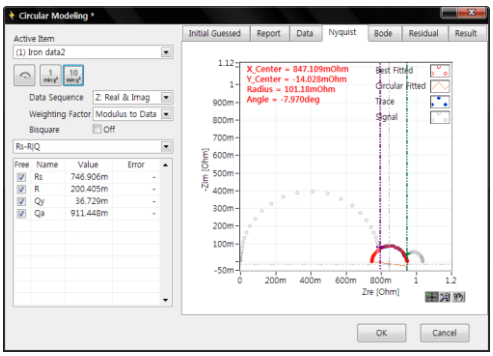


Figure 119. Other circle fitting

49. Circular fitting

Click fitting icon for 1 time or 10 time fitting 

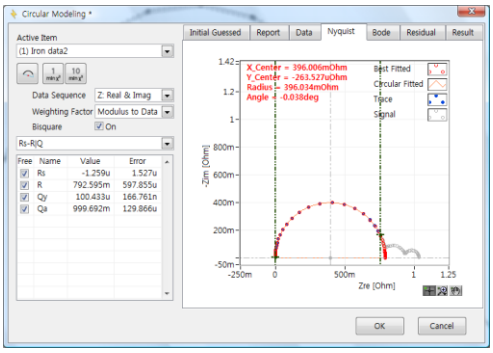


Figure 120. Fitting process

Fitting process is same as described in above modeling. See " **Modeling**" for details

50. Including Warburg impedance

If the circular data has Warburg diffusion element as simple circuit, you can select the model as the follows.

a. Select Model Rs-(R-W)|Q or Rs-(R-W)|C

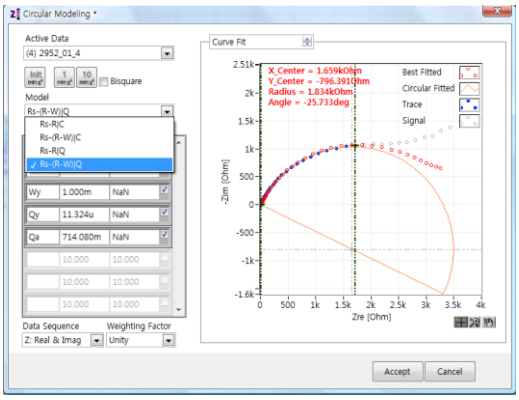


Figure 121. Model change

b. Move right(olive) cursor bar to linear region

c. Click fitting icon for 1time or 10 time fitting 

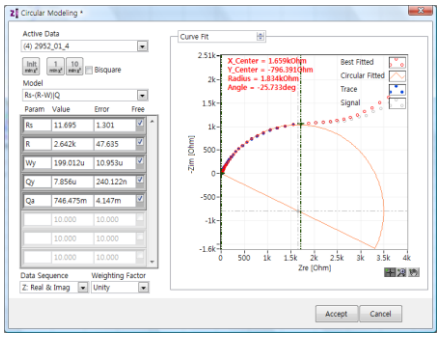


Figure 122. Fitting again

51. Circular fit result

You can see the data list, Report, Initial Guess information, Result, Residual, Bode as follows.

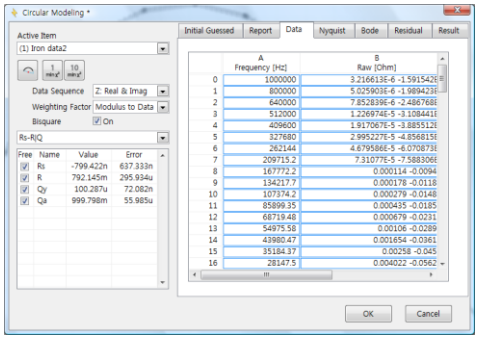


Figure 123. Data list

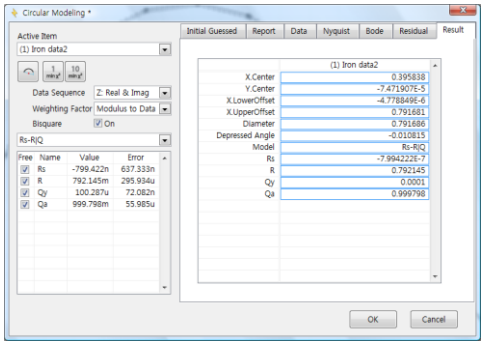


Figure 124. Circular fitting result display

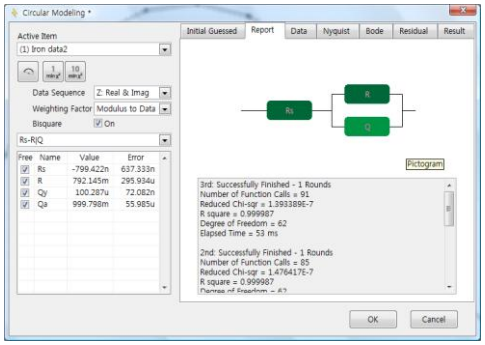


Figure 125. Circular fit report display

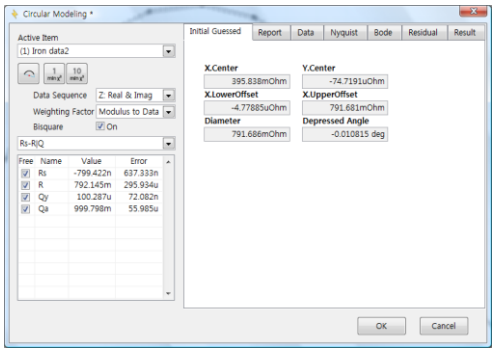


Figure 126. Initial guessing data

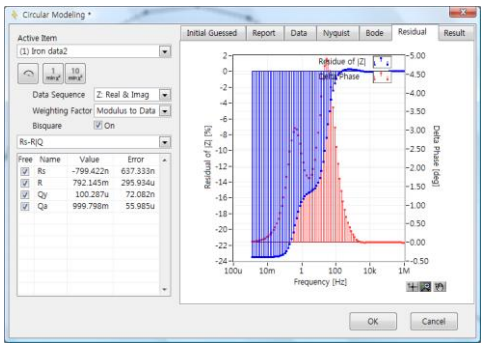


Figure 127. Residual

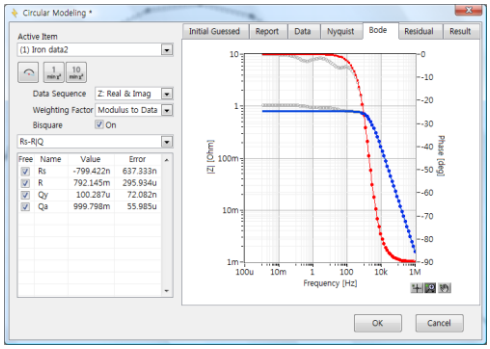


Figure 128. Bode plot overlay with result

Click accept button if you want use this parameters This fitting result parameter values will transfer to model parameter for Modeling and can be used as further fitting initial value. You can view fitted data in plots if you select raw data + fitted data.

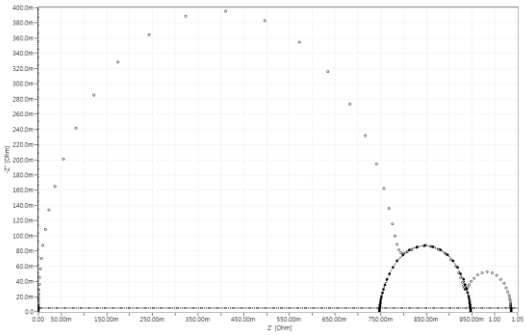


Figure 129. Raw data + circular fitted data in Nyquist plot after circular fitting

52. Circular fit result for Modeling

You can use these circular fitting result parameter values as fixed parameter and allow other parmeters to be free for further fitting operations. If there are 3 circles on Nyquist plot, you can do a circular fit for the 1st circle and can use this result for other 2 circle's fitting data in Modeling.

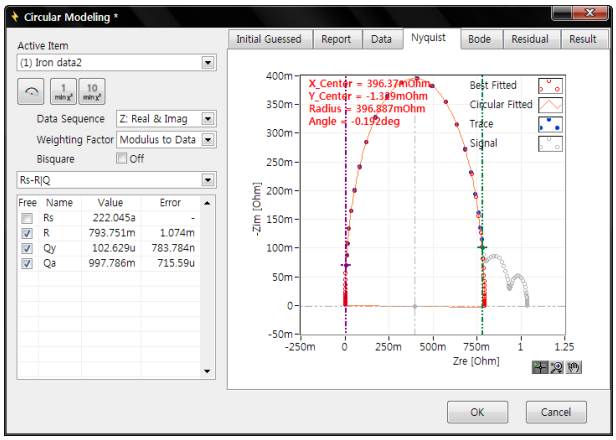


Figure 130. 1st circles circular fit

After the circular fit is completed, click OK button and enter Modeling menu. These fitting result values are automatically tranferred to Modeling.

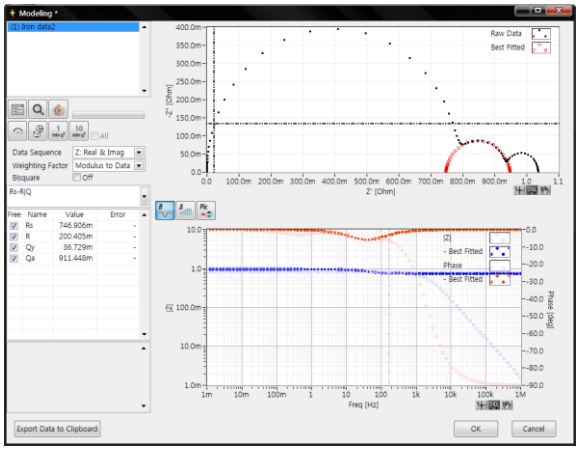


Figure 131. Circular fitting result transferred to Modeling

You can add additional Symbols to the current circuit formula.

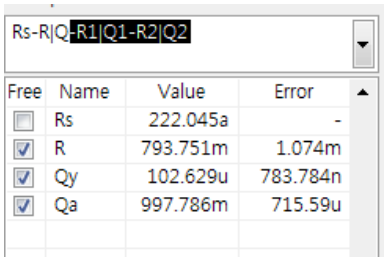


Figure 132. Adding Symbols for new model to fit

After entering additional symbols, press enter key, then adding symbol(parameter) list will displayed.

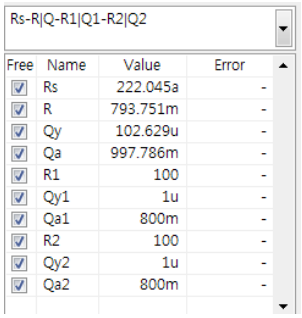


Figure 133. Added parameter list

You can fix Rs, R, Q to their current values by clicking Free parts.

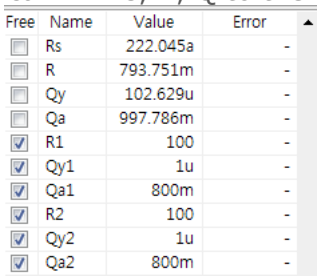


Figure 134. Fixed parameters from circular fit

Click simple circular initial guessing  or genetic analysis initial guessing  to set added parameters initial value.

Now you can do further fitting for other circles by clicking fitting buttons 

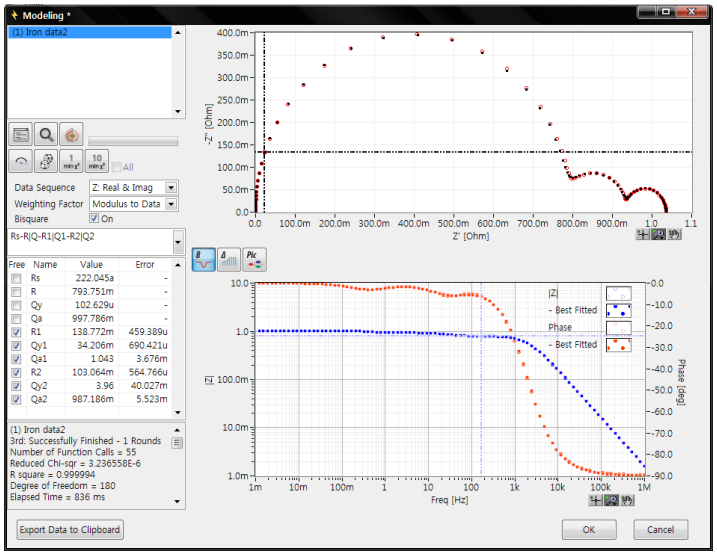


Figure 135. 1st Fitting result

Check free for parameters from circular fitting and click fitting button again.

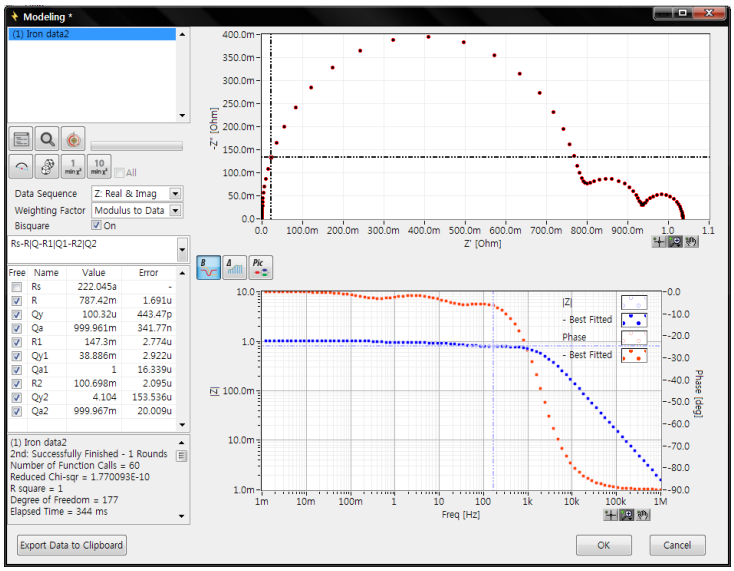


Figure 136. Final fitting result.

C. Manipulate element or Model

If you want to add or subtract element/circuit model from data, select Manipulation data model. You can select Add or subtract

If you select element or model in combo box or from model editor by clicking  and

input the value for manipulation, you can select subtraction or Addition of this value. You can input Model symbol directly but if there is such model in library, input is not available. You must make same model in model editor before doing this.

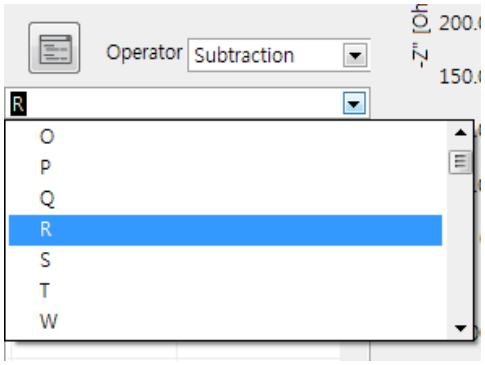


Figure 137. Select element or model for manipulation

53. Element subtraction/Addition

If you want to subtract a 6 kohm resistor from data, select R for element and input 6kohm, original data and subtracted data will be displayed as overlayed curves.

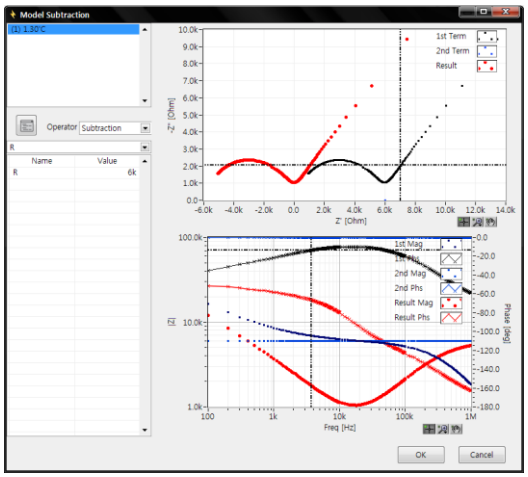


Figure 138. Manipulation result display

If you click Add & close, you can see the original data and the manipulated data at same time on the graph menu as the follows.

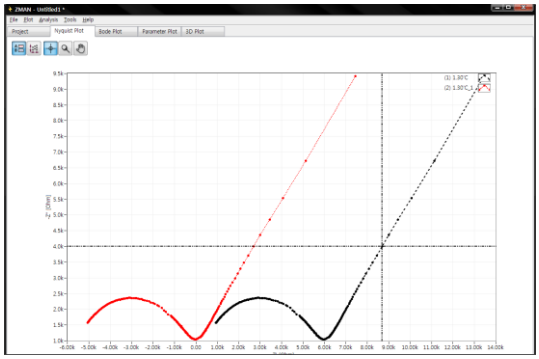
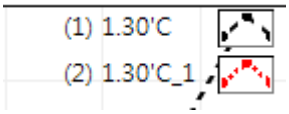
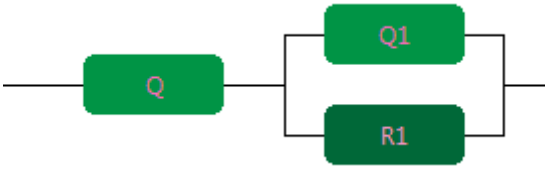


Figure 139. Overlay (original data and manipulated data)

Manipulated data will become a new data file by adding "_1" at end of original file name. This manipulated data can then be used for fitting etc independently.



The above data is assumed Q-Q1|R1



Q is straight line at right side and Q1|R1 is represented by the semi circle at left side. If you subtract Q from original data only the semi circle will remain.

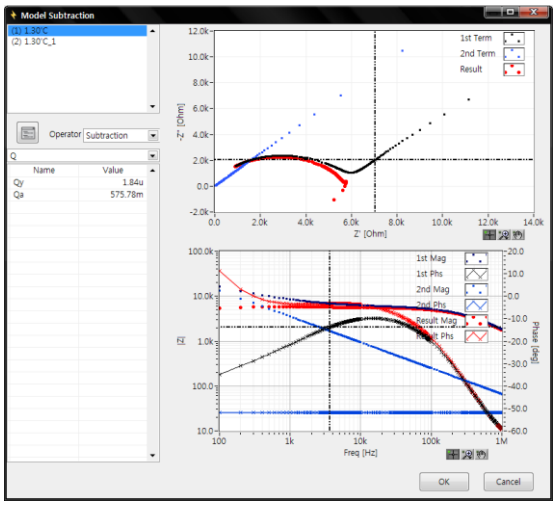


Figure 140. Q subtraction

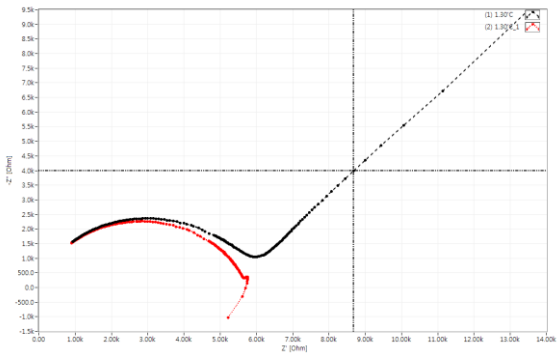


Figure 141. Q subtracted result (red line)

54. Model Subtraction/Addition

You can subtract or add model. For example If you subtract Q1|R1 model, straight line will remain.

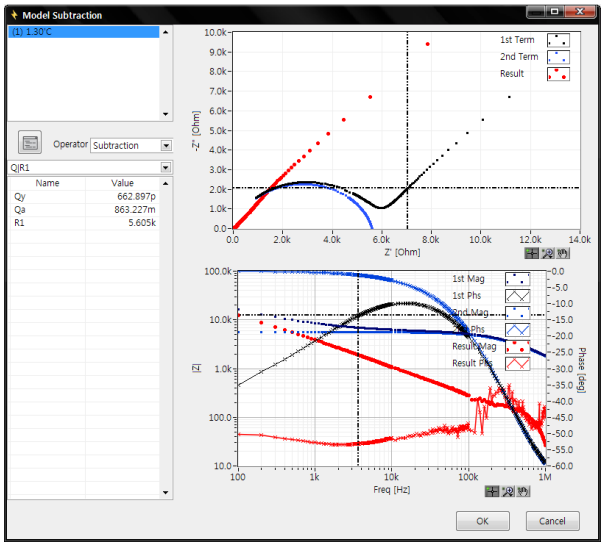
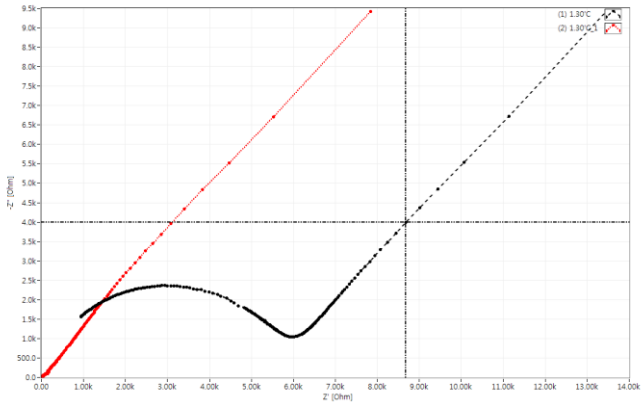


Figure 142. Q1|R1 subtraction



Q1|R1 subtracted result (red line)

Chapter 7 Equivalent Circuit Model Editor

You can use this menu to select the Model editor.

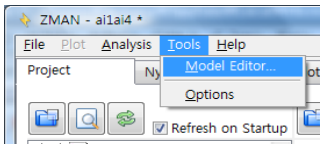


Figure 143. Model editor menu

When you select this function, an independent window is displayed.

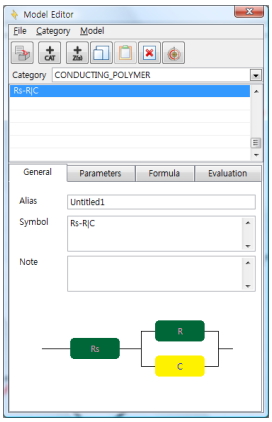


Figure 144. Equivalent Circuit Model Editor

A. Model file

You can backup/import/initialize model file as required.

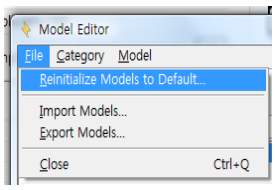


Figure 145. Model file menu

55. Reinitialize Models to Default

If you want to clear current models/categories and return to default conditions, then click this menu. You can see the warning message box.

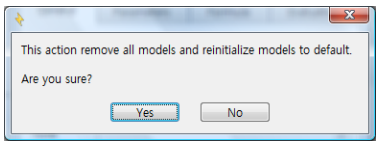


Figure 146. Confirmation of initialize model file

56. Import Models

If you want to import model/category from a backup file, an older ZMAN version model file or another person's model file generated using ZMAN, you can import it into current model file.

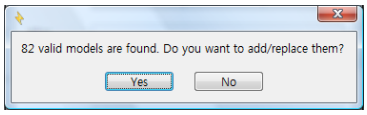


Figure 147. Model Importing

57. Export Models

Using this function, you can backup current model file including model/category information. Default file name format is "Backup(today's year-month-day-hour-minute-second).models"

B. Category Menu

There are several predefined categories for each application's library. You can define your own category(library). These categories will be used when you search for a model. You can search for a model in all categories or some category only.

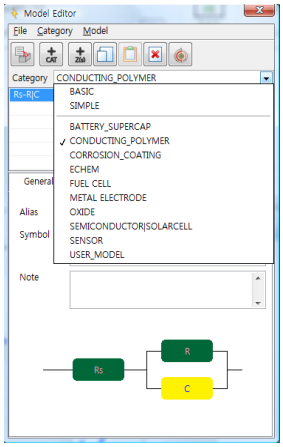


Figure 148. Predefined categories

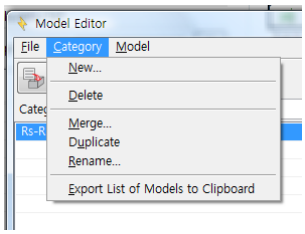


Figure 149. Category Menu

58. New category

If you want to define your own category(library), select New in Category menu.

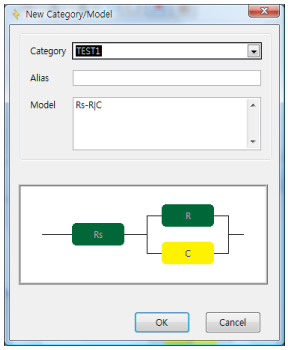


Figure 150. New category/model

You can input your category name(eg. Test1 etc) and the category will be created. (Note: Each category must contain a minimum of one model)

59. Delete category

If you want to delete a category which has models, Select Delete in Category menu.

Please note;

Deleted category with models **CANNOT** be recovered (permanently erased).
Before delete category, you must select category which you want to delete as the following window.

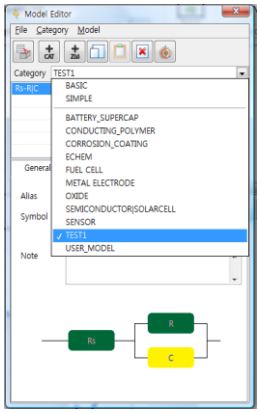


Figure 151. Delete category

And select delete in category menu the following window will appear.

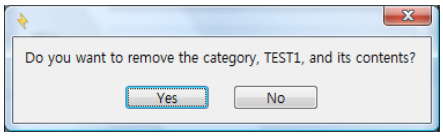


Figure 152. Delete confirmation box.

If the category has just one model, you can delete model then its category will be deleted.

60. Merge categories

If you want merge several categories into one new category, you can use this function.
Note: If you use this merge function, the source categories will disappear.

Example:

If you need to merge TEST1, TEST2, TEST3 categories into one TEST total category, select 3 categories in left window and click right side arrow to move these categories into the Selected box and change the New Category name as TEST total and click OK button. The 3 selected source categories will disappear and all models in 3 categories will move to a new category named TEST_total.

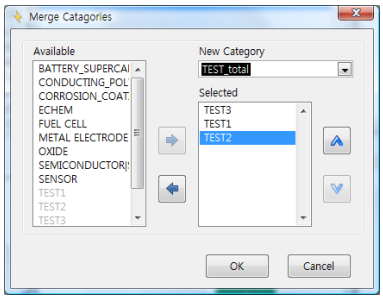


Figure 153. Merge Menu

When you click the OK button, you can see warning message as the follows

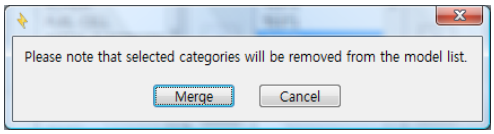


Figure 154. Merge confirmation

If you wish to confirm this merge, click the Merge button. TEST1, TEST2, TEST3 categories and their models will be erased and merged into TEST total.

61. Duplicate

This function will make a clone or copy of the source category.

62. Rename

This function renames a category.

63. Export list of models to clipboard

This function exports a copy the model list included in the source category into the clipboard.

C. Model Menu

Each category can contains several models (equivalent circuit model). Each model can be included in multiple categories with different default parameter value to meet each application.

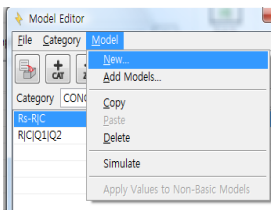


Figure 155. Model Menu

64. New

You can make a new model by clicking Model-New on the menu or clicking Model New button. New model editor will be displayed as the follow.

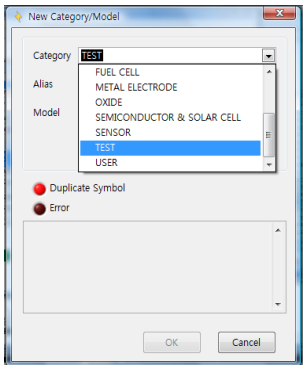
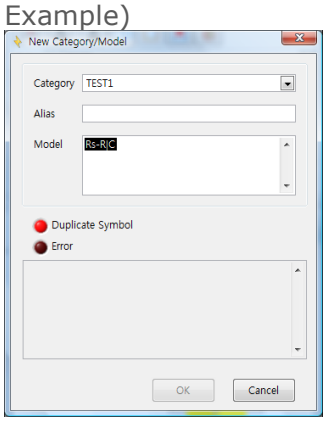


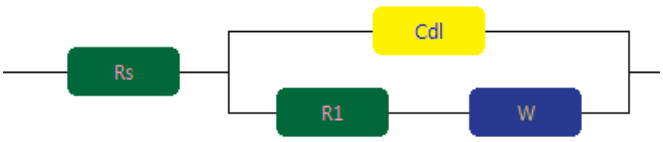
Figure 156. New Model/Category Menu

Firstly you must select Category where you want the new model created.
If you need to define a new category, just type on Category input and a new category will be created.

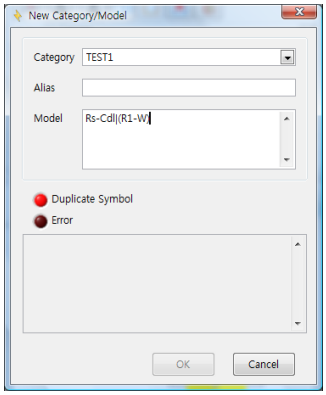
Example)



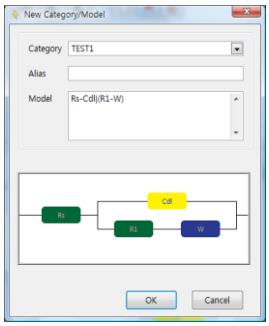
If you selected Category, input the model following Model editor rule described in the following "model design rules".



If you want to make the above equivalent circuit model, type "Rs-Cdl|(R1-W)" on Model input and enter key or click other part.

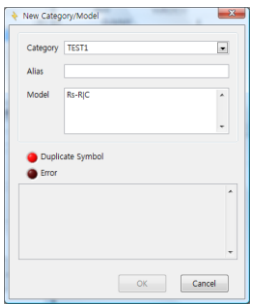


If there are no errors in your definition, the following window will be displayed.



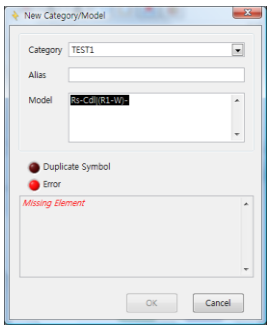
If you click OK button, this model will be saved in TEST1 category.

If there are errors in the Model description, the following errors will be displayed.



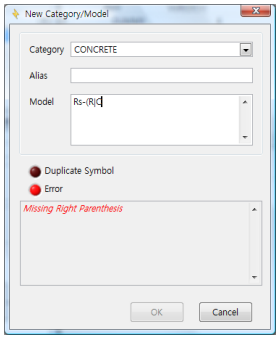
An identical model in target category will report an error.

Figure 157. Duplicated Model



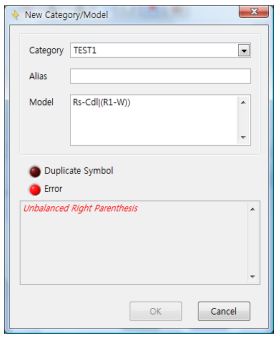
If an element is missing, the above error will be displayed.

Figure 158. Missing element



Needs Right Parenthesis to complete the formula.

Figure 159. Missing Right Parenthesis



There is missing left Parenthesis on the formula.

Figure 160. Unbalanced Right Parenthesis

65. Add Models

You can add model(s) into a category by typing symbols or pasting a model list if you previously performed an: "Export list of Models to clipboard" in the category menu. Before this action, you must first select your target category.

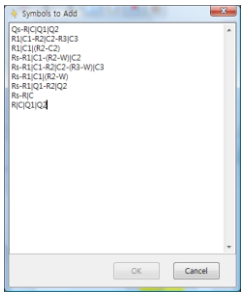


Figure 161. Symbols to add

After typing or pasting the symbol list as described above, click OK button and the following box will appear. If a valid model exist, the model color will be change to blue and OK button activated. When you click OK button, valid models will be added to target category.

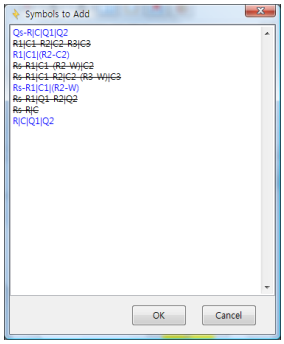


Figure 162. Model check for symbol to add

66. Model Copy

If you want to copy a model to paste into other category, click model copy icon or select copy on Model menu.

67. Model Paste

If you copied a model, you can paste it into other categories.

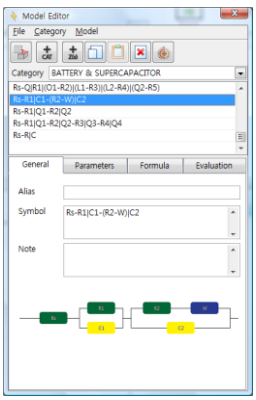
68. Model Delete

You can delete the model in a specified category. Same model in other categories will NOT be erased.

69. Model Edit/Create

You can edit a model's parameter default value, alias, note field without making it a new model. If you modify model symbols(model circuit), software will accept it as new model.

a) Model Edit



You can input information in Alias by typing (It may be used as a comment for application). Also you can input information in Note field. If you double click on Note field, new memo window will be displayed.

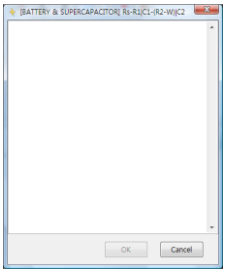
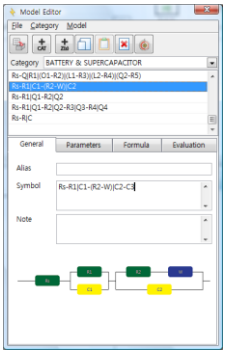


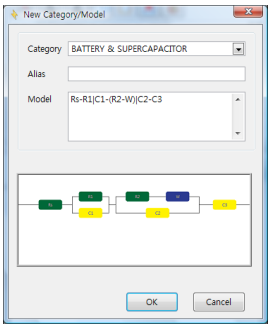
Figure 163. Memo input window.

b) Model create

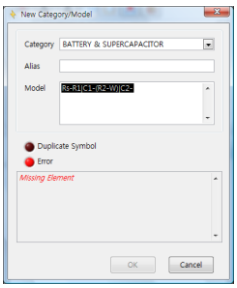
If you want to create a new model by modifying a current model, ZMAN will recognize it as a new model.
E.g. If you add C3 as serial connection, then type "-C3" at the end of the model formula and press enter key. This will add a Capacitor (C3) to the end of the original model.



If there is no error in symbol connection then the following New category/Model window will appear.



But if there is an error, the following error message will appear.



D. Model Design Rules

An equivalent circuit is made of a combination of circuit functions or elements. ZMAN provides 12 basic circuit functions. See **Basic Elements** for details. If you want to have your own circuit function, refer to **Single Elements.**

In ZMAN, a circuit model is described as symbols of functions and 4 special operators standing for relation of functions or their combinations. You can identify each symbols with an ASCII characters (0 to 9, a to z, and A to Z) next to symbols such as R1, R2, and Rs.

Those 4 operators are

"- " Serial Operator.
For example, "R-C" means a resistor serially connected with a capacitor.

"+" operator can be used instead of "-"operator.

"| " Parallel Operator.
For example, "R|C" means a resistor is connected in parallel with a capacitor.

"/" operator can be used instead of "|" operator.

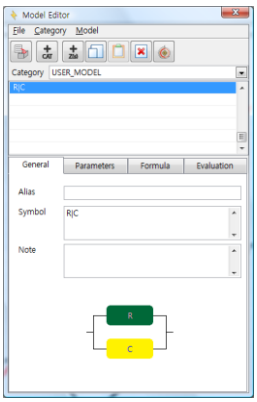


Figure 164. Equivalent Circuit Model Editor

"(xxx)" Left and Right parentheses –Parallel Operators are used to clearly define a group of elements. For example, "Rs-(Rct|Cdl)" means a resistor (Rs) serially connected with a resistor (Rct) and a capacitor connected in parallel.

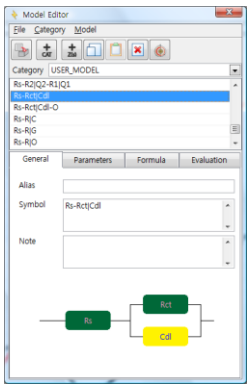


Figure 165. Rs-(Rct|Cdl)

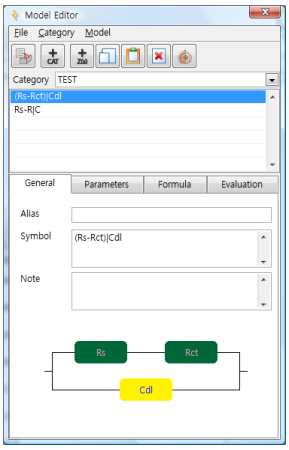


Figure 166. (Rs-Rct)|Cdl

In ZMAN, the Parallel Operator has a higher priority than the Serial Operator similar to the * and + operators in normal Arithmetic operations. It is quite natural that Parentheses operators are the highest among them. This means, if a circuit is expressed as "L-(R|C)", then "L-R|C" is equivalent in ZMAN.
Example) Complicated model designing

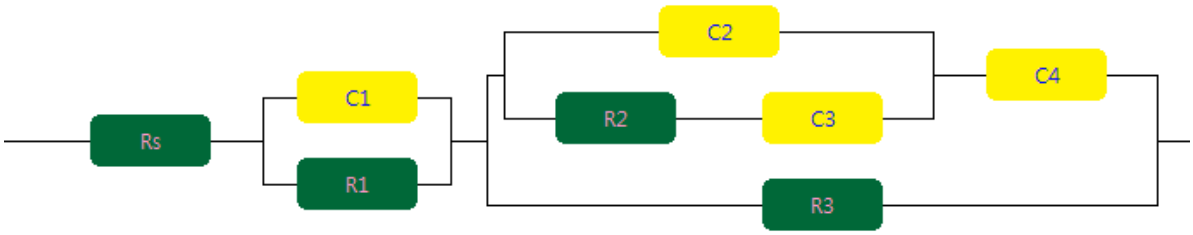


Figure 167. Sample Model

The above circuit can be grouped as the follows. Each group should be identified by Parenthesis.

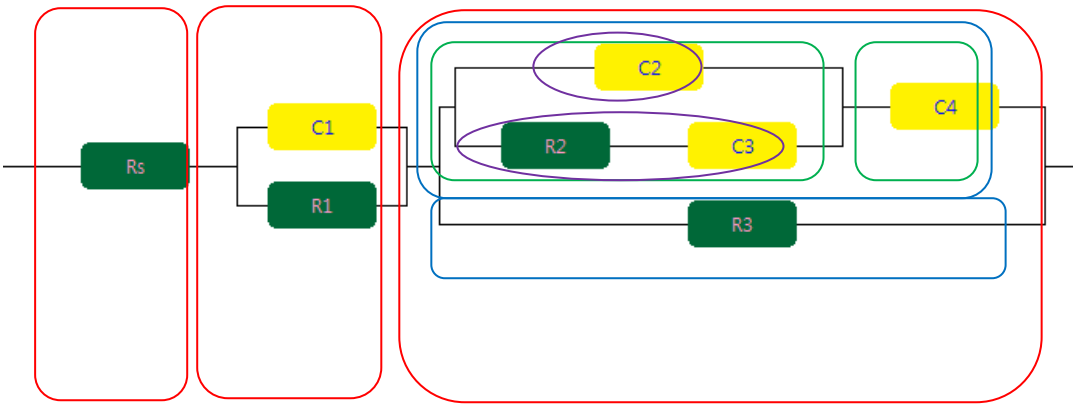


Figure 168. Sample model group analysis

1st step: Red group is;
Rs-(C1|R1)-(blue group)

2nd step: Blue group is
Rs-(C1|R1)-((Green group)|R3)

3rd step: Green group is
Rs-(C1|R1)-(((violet group)-C4)|*R3*)

4th step: Violet group is
Rs-(C1|R1)-(((C2|(R2-C3))-*C4*)|*R3*)

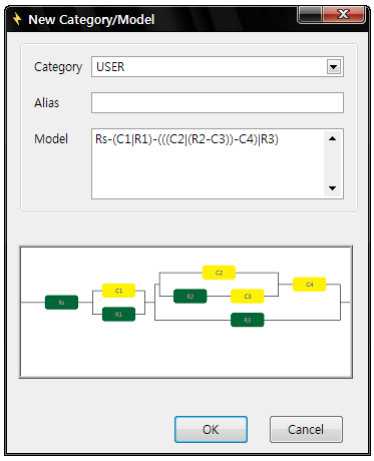


Figure 169. Check the symbol for sample model designing

70. Basic Elements

There are 12 basic elements in the BASIC category which are already defined in ZMAN software. These elements cannot be deleted nor modified.
When you click the right button of mouse in the symbol area, an element pop up menu will appear as the follows.

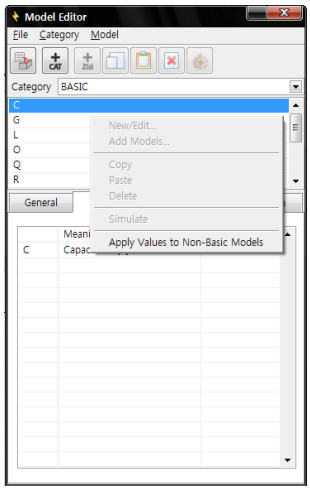


Figure 170. Basic element

You can change parameter default value and it can be applied to other categories as their default value by selecting "Apply Values to Non-Basic Models"

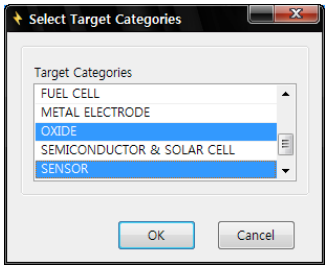


Figure 171. Default parameter value change in target category

Each element in Basic category

Note: s represents jw, where j is imaginary unit, $\sqrt{-1}$, and w is angular frequency.

71. Resistive Element

Symbol: R
Parameter(s): R
Formula: $Z_R = R$

72. Capacitive Element

Symbol : C
Parameter(s): C
Formula: $Z_C = \frac{1}{sC}$

73. Inductive Element

Symbol: L
Parameter(s): L
Formula: $Z_L = sL$

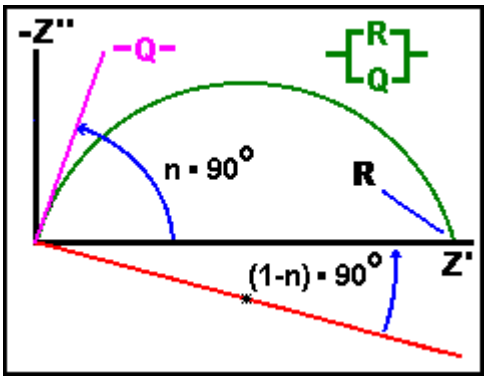
74. Constant Phase Element (CPE)

Symbol : Q
Parameter(s): Qy, Qa
Formula: $Z_Q = \frac{1}{Q_y s^{Qa}}$

The Constant Phase Element (CPE) is a non-intuitive circuit element that was discovered (or invented) while looking at the response of real-world systems. In some systems the Nyquist plot (also called the Cole-Cole plot or Complex Impedance Plane plot) was expected to be a semicircle with the center on the x-axis. However, the observed plot was indeed the arc of a circle, but with the center some distance below the x-axis. These depressed semicircles have been explained by a number of phenomena, depending on the nature of the system being investigated. However, the common thread among these explanations is that some property of the system is not homogeneous or that there is some distribution (dispersion) of the value of some physical property of the system.

Mathematically, a CPE's impedance is given by

$1 / Z = Y = Q° (j \omega)^n$
where Q° has the numerical value of the admittance (1/ |Z|) at ω=1 rad/s. The units of Q° are $S \cdot s^n$ (*ref 1*).



When n=1, this is the same equation as that for the impedance of a capacitor, where Q° =C.
$1 / Z = Y = j \omega Q° = j \omega C$
When n is close to 1.0, the CPE resembles a capacitor, but the phase angle is not 90°. It is constant and somewhat less than 90° at all frequencies. In some cases, the 'true' capacitance can be *calculated* from Q° and n
The Nyquist (Complex Impedance Plane) Plot of a CPE is a simple one. For a solitary CPE (symbolized here by **Q**), it is just a straight line which makes an angle of (n*90°) with the x-axis as shown in **pink** in the Figure. The plot for a resistor (symbolized by **R**) in parallel with a CPE is shown in **green**. In this case the center of the semicircle is depressed by an angle of (1-n)*90°
http://www.consultrsr.com/resources/eis/cpe1.htm

75. Warburg Diffusion

Symbol : W
Parameter(s): Wy
Formula: $$Z_W = \frac{1}{W_y \sqrt{s}}$$

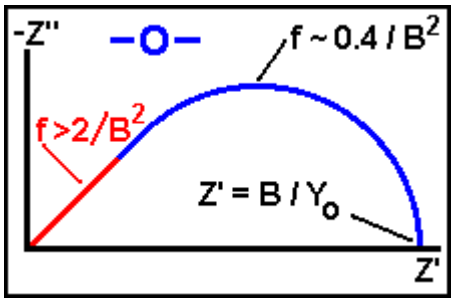
The most common diffusion circuit is the so-called "Warburg" diffusion element, but it is not the only one! A Warburg impedance element can be used to model semi-infinite linear diffusion, that is, unrestricted diffusion to a large planar electrode. This is the simplest diffusion situation because it is only the linear distance from the electrode that matters.
The Warburg impedance is an example of a constant phase element for which the phase angle is a constant 45° and independent of frequency. The magnitude of the Warburg impedance is inversely proportional to the square root of the frequency ($1/\omega^{1/2}$) as you would expect for a CPE with an **n**-value of 0.5. The Warburg is unique among CPE's because the real and imaginary components are equal at all frequencies and both depend upon $1/\omega^{1/2}$
http://www.consultrsr.com/resources/eis/diffusion.htm

76. Diffusion Circuit Element

Symbol : O
Parameter(s): Oy, Ob
Formula: $$Z_O = \frac{1}{O_y \sqrt{s}} \tanh[O_b \sqrt{s}]$$

The most commonly used diffusion circuit element is the Warburg, but it is not always the most appropriate one! It is often wise (and fairly common) to use a **rotating disk electrode** (RDE) in impedance studies. It is particularly wise when studying reactions involving diffusing species when the "DC" current is different than zero -- studies at

potentials away from the open circuit or equilibrium potential (away from the rest potential or the corrosion potential:). If a stationery electrode and unstirred solution were used instead, the current would slowly decay. The changing and non-steady state "DC" current would corrupt the interpretation of the lower frequency measurements. In systems such as the RDE, there is a region close to the electrode in which mass transport happens only by diffusion. Outside of this "Nernst Diffusion Layer" the solution is homogeneous due to the stirring produced by the rotating electrode assembly. The concentration of the diffusing species in the bulk solution remains unchanged by the experiment (i.e., the reaction vessel is big!) The material simply diffuses through the Nernst Diffusion Layer (NDL) to reach the electrode. The impedance in this case is described by the so-called **O** circuit element. The RDE is not the only case where the **O** element might be seen. Often the rate of corrosion is limited by the slow diffusion of oxygen through a coating or a passive film. This situation is quite similar to the RDE example, above. The oxygen concentration is homogeneous in the solution phase due to mixing and the concentration just outside the coating or film is fixed and constant. The impedance in this example also fits the **O** element model



The figure to the left shows the Nyquist plot for the **O** diffusion element. The **O** element is characterized by two parameters, an "admittance" parameter, $\mathbf{Y_o}$, and a "time constant" parameter, **B** (units: $sec^{1/2}$). At high frequency ($f > 2 / B^2$) the **O** circuit element is indistinguishable from a Warburg impedance! This frequency range is shown in **red** in the figure. Since the time for a molecule to diffuse across the thin layer is much longer than the period of the AC stimulus applied, the electrode does not 'see' that the film or coating is of finite thickness.

Equations for the O element.
The equations for the complex admittance ($Y(\omega)$) and complex impedance ($Z(\omega)$) are given by the equations below. The O circuit element gets its name from the hyperbolic cotangent (coth[]) admittance response.

$$\vec{Z}(\omega) = \left\{\frac{1}{Y_0\sqrt{j\omega}}\right\}\tanh\left[B\sqrt{j\omega}\right] \qquad \vec{Y}(\omega) = \left\{Y_0\sqrt{j\omega}\right\}\coth\left[B\sqrt{j\omega}\right]$$

Yo has the same *definition* as for the Warburg impedance. **Yo** can be used to calculate a diffusion coefficient for the mobile species **within** the film, coating, or in the NDL using the same *equations*. For large values of the argument (the **red** region of the Nyquist plot, above), the tanh and coth functions both approach unity and the impedance has the same ω dependence as the Warburg. This region can be used to estimate **Yo**.
If the thickness of the NDL (for RDE) or the thickness of the film is δ, then the constant **B** is related to that thickness and the diffusion coefficient, D. **B** characterizes the time it takes for a reactant to diffuse through the NDL or thin film.

$$B = \delta / \sqrt{D}$$

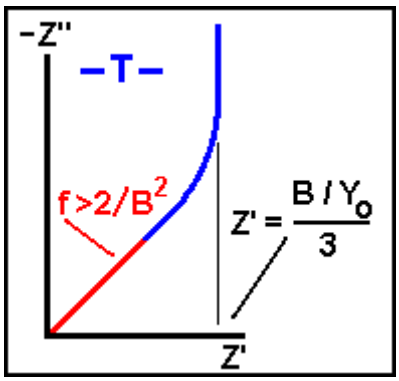
(http://www.consultrsr.com/resources/eis/diff-o.htm)

77. Finite Diffusion

Symbol : T
Parameter(s): Ty, Tb

Formula: $$Z_T = \frac{1}{T_y\sqrt{s}}\coth[T_b\sqrt{s}]$$

The **T** circuit element is characteristic of another type of film -- a film which contains a fixed amount of electroactive substance. The classical "thin layer electrochemistry" cell is an example of such a system. Batteries or supercapacitors also may share this behavior. The common feature is the fixed amount of electroactive material present. Once it has been consumed, it can not be replenished.



A Nyquist plot for the **T** element

The figure to the left shows the Nyquist plot for the **T** diffusion element. Like the O element, the **T** element is characterized by two parameters, an "admittance" parameter, $\mathbf{Y_o}$, and a "time constant" parameter, **B** (units: $sec^{½}$). At high frequency (f > 2 / $\mathbf{B}^2$) the **T** circuit element is indistinguishable from a Warburg impedance! This frequency range is shown in redi in the figure. Since the time for a molecule to diffuse across the thin layer is much longer than the period of the AC stimulus applied the electrode does not 'see' that the film or coating is of finite thickness.

At low frequency, the **T** element looks like an R and a C in series, with R=(**B** / **Yo**) / 3

The equations for the complex admittance (Y(ϖ)) and complex impedance (Z(ϖ)) are given by the equations below. The T circuit element gets its name from the hyperbolic tangent (tanh[]) admittance response.

$$\vec{Z}(\omega) = \left\{\frac{1}{Y_0\sqrt{j\omega}}\right\}\coth\left[B\sqrt{j\omega}\right] \qquad \vec{Y}(\omega) = \left\{Y_0\sqrt{j\omega}\right\}\tanh\left[B\sqrt{j\omega}\right]$$

Yo has the same definition as for the Warburg impedance. Yo can be used to calculate a diffusion coefficient for the mobile species within the film, coating, or thin layer cell using the same equations. For large values of the argument (the red region of the Nyquist plot, above), the tanh and coth functions both approach unity and the impedance has the same ϖdependence as the Warburg. This region can be used to estimate **Yo**.
If the thickness of the thin layer is δ, then the constant B is related to this thickness and the diffusion coefficient, D. The parameter B characterizes the time it take for a reactant to diffuse from one side of the layer to the other.

$$B = \delta/\sqrt{D}$$

http://www.consultrsr.com/resources/eis/diff-t.htm

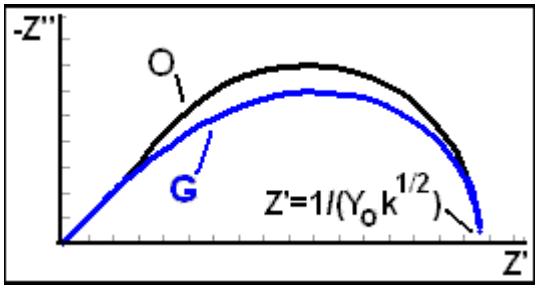
78. Homogeneous Reaction(Gerischer)

Symbol : G
Parameter(s): Gy, Gk
Formula: $$Z_G = \frac{1}{G_y\sqrt{G_k + s}}$$

The Gerischer (**G**) circuit element was first derived for a preceding chemical reaction happening in the bulk solution. This is the so called **CE** mechanism.

$$A \xrightarrow{k} Ox \xrightarrow{ne^-} Red$$

A Gerischer has also been used to model a porous electrode (*ref 2*).
On a Nyquist plot, it looks quite a lot like the *O diffusion element* (diffusion through a thin layer).



A Nyquist plot for the **G** element. It is not as high as an **O** element with the same intercept. The value of the low frequency intercept for the Gerischer is shown.

The figure to the left shows the Nyquist plot for the **G** diffusion element. The **G** element is characterized by two parameters. an "admittance" parameter, $\mathbf{Y_o}$ (units $S\text{-}s^{1/2}$), and a "rate constant" parameter, **k** (units: s^{-1}). At high frequency the **G** circuit element is indistinguishable from a *Warburg* impedance! At high frequency, it presents a 45° line on the Nyquist plot and a straight line with slope of -1/2 on the Bode magnitude plot

The equations for the complex impedance ($Z(\omega)$) and complex admittance ($Y(\omega)$) are given by the equations below. (*Ref 1*)

$$\vec{Z}(\omega) = 1/\left\{Y_0\sqrt{k + j\omega}\right\} \qquad \vec{Y}(\omega) = Y_0\sqrt{k + j\omega}$$

Yo has the same definition as for the *Warburg* impedance. **Yo** can be used to calculate the diffusion coefficient for the mobile species using the same *equations* as for the Warburg. The high frequency region can be used to estimate **Yo**
http://www.consultrsr.com/resources/eis/gerischer.htm

79. Spherical Diffusion

Symbol : S
Parameter(s): Sy, Sk
Formula: $$Z_S = \frac{1}{S_y}\frac{1}{\sqrt{S_k} + \sqrt{s}}$$

80. Finite-Length diffusion at planar particles

Symbol : X
Parameter(s): Xr, Xc
Formula: Zx=sqrt(3*Xr/Xc/s)*CotH(sqrt(3*Xr*Xc*s))

81. Finite-Length diffusion at spherical particles

Symbol : Y
Parameter(s): Yr, Yc
Formular:Zy=Tanh(sqrt(3*Yr*Yc*s))/(sqrt(3*Yc*s/Yr)-Tanh(sqrt(3*Yr*Yc*s))/Yr)

82. Finite-Length diffusion at cylindrical particles

Symbol : Z
Parameter(s): Zr, Zc
Formular:
Zz=Zr*BesselI(0,sqrt(2*Zr*Zc*s))/sqrt(2*Zr*Zc*s)/BesselI(1,sqrt(2*Zr*Zc*s))

E. Simple elements

Simple element is a User defined element. User can define specific symbol as functional element in SIMPLE category. Note: It is for only advanced users. If you want to use this function of ZMAN, please make contact with us.

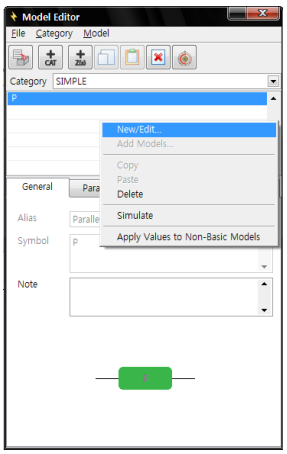


Figure 172. Simple category editing.

83. New/Edit element

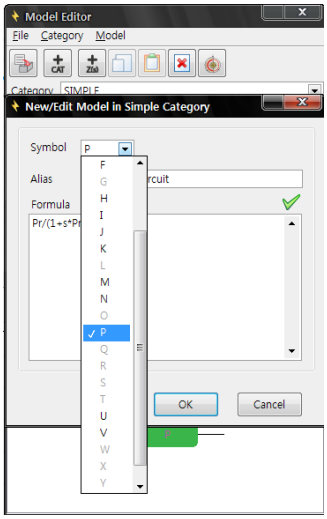


Figure 173. New/Edit Model in simple category

Select one Symbol. Available Symbols are one among A, B, D, E, F, H, I, J, K, M, N, P, U and V. Valid symbol is dark and used symbol is grey

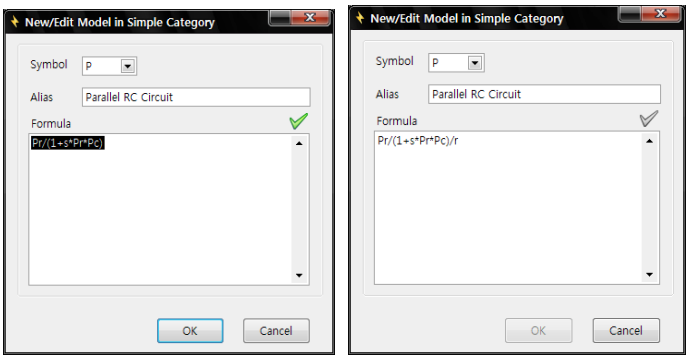


Figure 174. Formula input for user defined model.(Left: formula correct)

Type "Pr/(1+s*Pr*Pc)" in the Formula tab. If the formula is correct, then green check mark will appear but if it is incorrect then check mark's color will be changed to grey. and click OK button

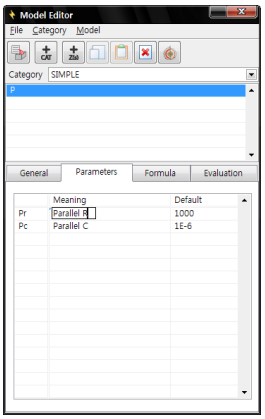


Figure 175. Default parameter input

Input each default value in the table of Parameter tab and type each parameter's meaning.

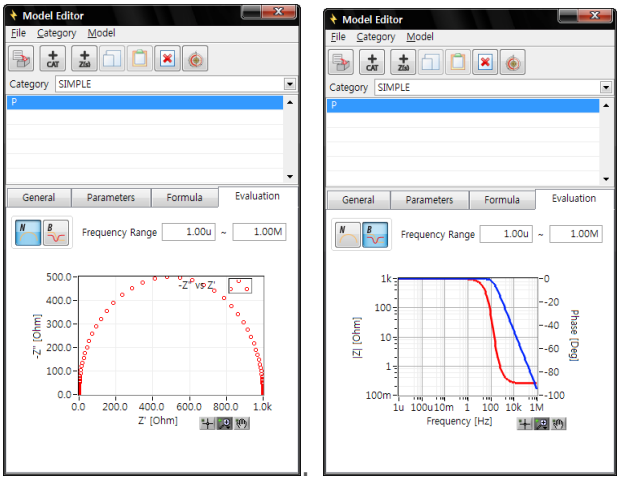


Figure 176. Evaluation tab

Click **Save** to save it.

84. Delete element

Click Delete to erase element in Simple category

85. Apply values to Non-Basic Models

You can change parameter default value and it can be applied to other category as their default value by selecting "Apply Values to Non-Basic Models"

F. Parameter Simulation

ZMAN provides unique simulation function. This function can display multiple impedance spectra following parameter value change as matrix.
There are two way to simulate.

86. From Model editor

This function can be used for default parameter change for the selected model or for the study of the impedance spectra for the selected model. You can select model in the model editor for simulation.

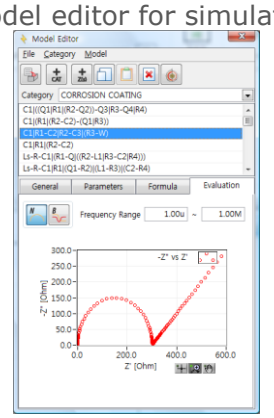


Figure 177. Model selection for simulate

Click simulation button  the simulation window will appear.

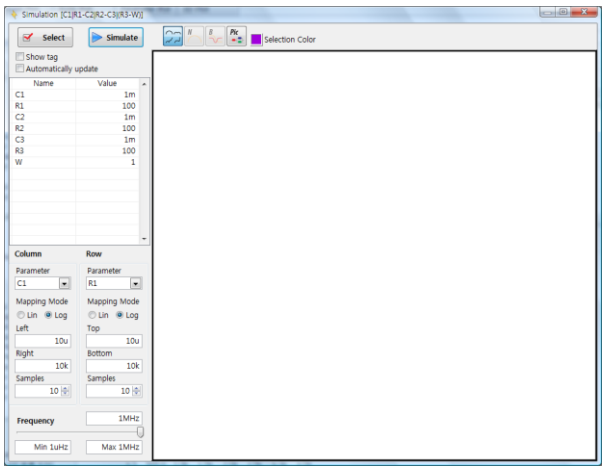


Figure 178. Parameter simulation window

a) Select parameter

You can select two parameters to view simulation result subject to the changes in these parameters.

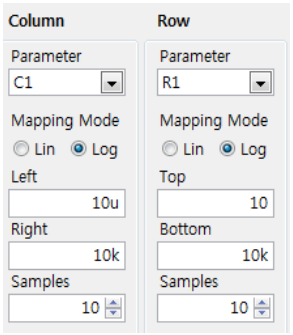
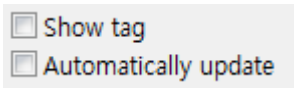


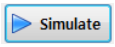
Figure 179. Parameter selection

1) You can select log scale or linear scale for matrix.
2) Parameter value range setting: Max. Min value for simulation
3) You can change matrix value for X, Y samples (default value is each 10).

b) Simulation



1) Show tag: If you checked on show tag, matrix simulation spectra will be displayed with X,Y value.
2) If you check on Automatic update, then simulation will be done automatically whenever you change the parameter.

If you did not check on above two check box then when you click 

button, you can see simulated matrix view.

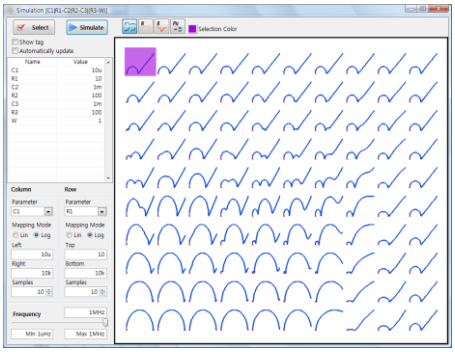


Figure 180. Parameter matrix display

c) Frequency range for simulation

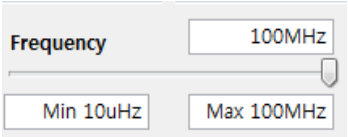


Figure 2. Frequency range

You can extend frequency range by input minimum frequency and Maximum frequency at left bottom side.

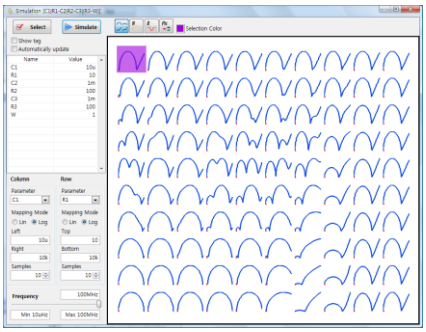


Figure 181. Change frequency range 10uHz to 100MHz for simulation

d) Selected Spectra

You can select one of simulated spectra by clicking on it. Selected color can be changed.

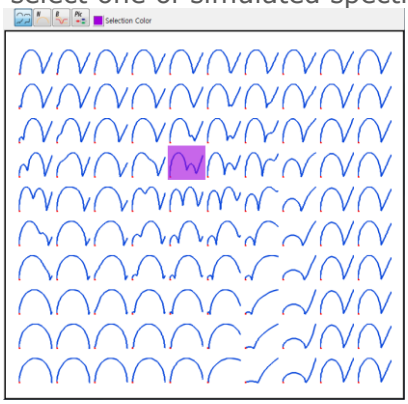
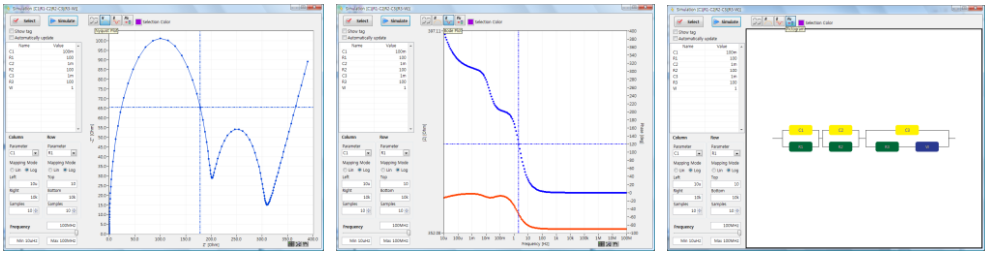


Figure 182. Simulated spectra selection

If a spectrum was selected, its parameter values will be displayed at left side parameter information. You can also see bode, Nyquist plot or model pictorial for selected spectra by clicking one of buttons. 



e) Model default parameter value

If you selected a spectrum in simulation and click 

button, then the selected spectra's parameter values will be saved as the model's default value. If you do not want to change model's parameter default value inside the category, do NOT click 

button.

87. From data fitting

This function can be used for determining initial parameter value for further fitting or for study the impedance spectra for the selected mode. You can enter simulation from fitting result.

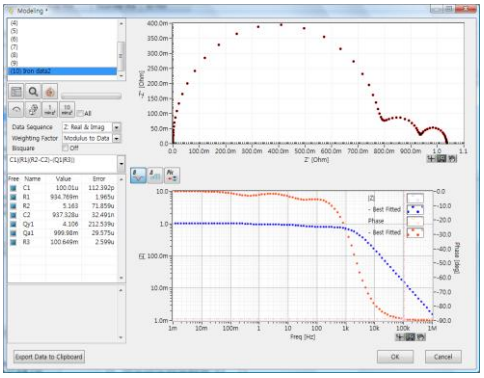
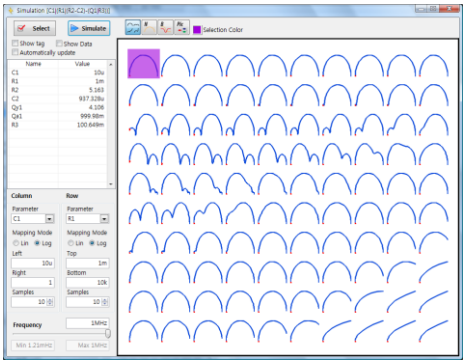


Figure 183. Fitting result

Click simulation button  the simulation window will appear.



If you check on show data, you can see simulated spectra(blue color) with raw data(grey color).

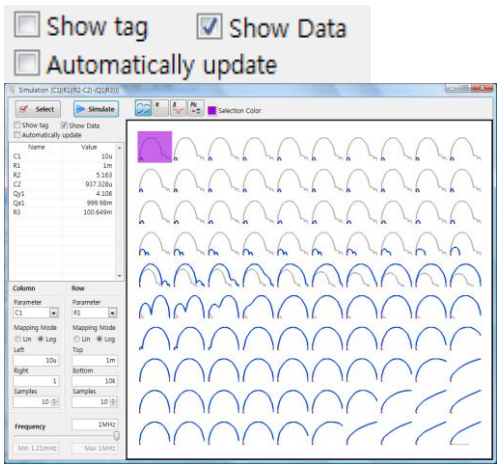


Figure 184. Matrix simulated spectra with raw data

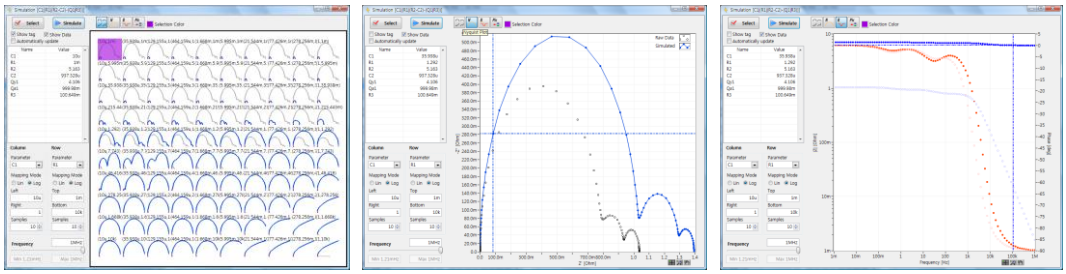


Figure 185. Simulated graphic display

Regarding other functions, refer to the above "1. From the model".
If you selected a simulated spectra and click select button, its parameters will be transfer to fitting menu. You can fit from these initial parameter values.

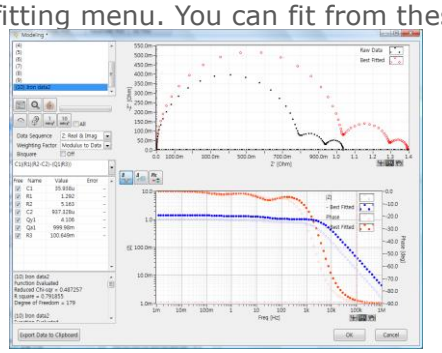


Figure 1 Fitting display

Chapter 8 Automatic Model Search

ZMAN has a unique function namely Automatic Model Search. Users who are not familiar with EIS models can find suggested models which are better fitted to their data.
To do an Automatic Model Search, you need to upload your data to project.
And select Analysis-Modeling in menu.

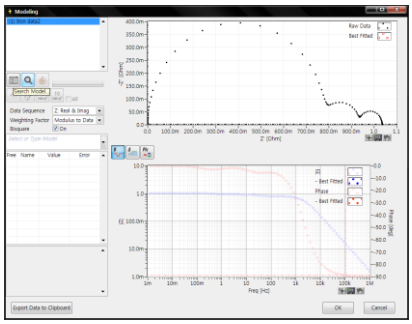


Figure 186. Automatic Model search selection

A. Searching Parameter Setting

Click search model button then the following box will appear.

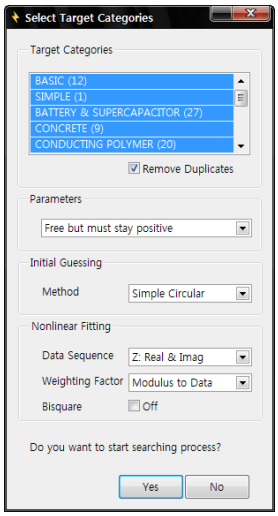


Figure 187. Automatic Searching Condition

88. Target Category selection

You can select single category or multiple categories which will be used for searching.
Default selection is all categories selected. It will take longer time to search models than with selection of single category.

Option: Remove duplicates On/Off
If this option is ON, duplicated model in various categories will be skipped in searching.

If user make their own categories which contains proper models for their test, searching time will do not take long time to get best result.

If you want to use multiple categories for searching, select categories by mouse click under pressing ctrl key

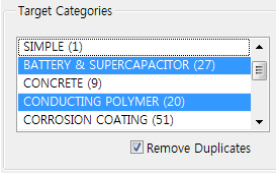


Figure 188. Multiple categories selection

89. Parameter value range

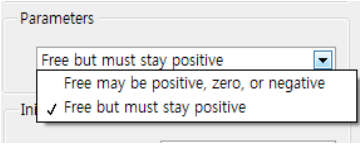


Figure 189. Parameter range selection

You can select searching condition in parameter value range.
If you select "Free may be positive,zero, or negative", Fitting parameter value can be under zero value (artificial value).
If you want positive value only for parameter value, you must select "Free but must stay positive"

90. Initial guessing method

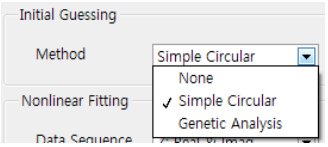


Figure 190. Initial guessing method selection

There are 3 methods.

a) None: If you select None, Searching process will start from default parameter value in each model

b) Default method is Simple circular method. This is assumed that nyquist plot contains circular shape and finding initial value to start fitting.

c) Genetic Analysis: This method applies a random value matrix as initial value and attempts to find proper initial value. It takes much longer time than simple circular method. If you fail to find proper model, you may use this method.

With Simple circular method or Genetic analysis method, parameter default value in model will not used.

91. Non linear fitting

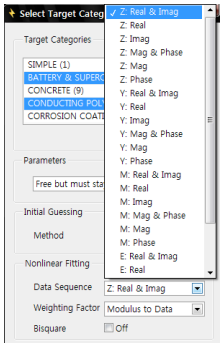


Figure 191. Non linear fitting

a) Data sequence

You can select data set which will be used for non linear fitting.
Default data set is Zreal & Zimg.(Nyquist)
For some data, you can use Zmag & Zph (Bode)

b) Weighting factor

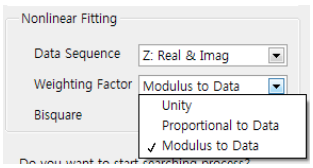


Figure 192. Weight factor selection

You can select weighting factor as unit, proportional to data or Modulus to data.
Default setting is Modulus to data

c) Bisquare

Bisquare obtains the slope and intercept using an iterative process and calculates the residue using the same formula as in the Least Square method. This option takes longer time but more accurate.
Default setting is off.

When you select searching condition, click OK button then searching process will start.

B. Model finding Criteria Setting

You can set model finding criteria for model searching by selecting options in Tools.

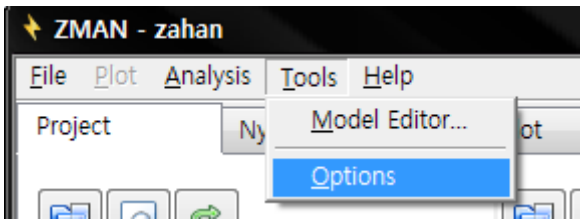


Figure 193. Option Menu

92. For Simple circular initial quessing and no initial guessing

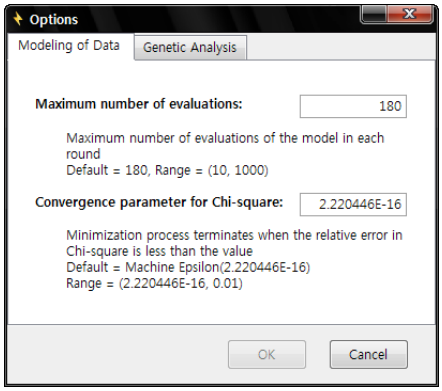


Figure 194. Modeling of Data for searching criteria

If you select no initial guessing or simple circular initial guessing for automatic model searching, you can set limit criteria for ZMAN to determine the model.

a) Maximum number of evaluations; Default value (180)

This setting value is maximum number of evaluations of the model initial guessing and fitting in each round.
Input number range: Minimum 10 to Maximum 1000
If you input larger number, the searching result is more accurate but it takes much longer time.

If the fitting result in Chi-square meet following "Convergence parameter for Chi-square" before setting "Maximum number of evaluations" number, Model searching to move to next model.

b) Convergence parameter for Chi-square; Default value (2.220446E-16)

Minimization process terminates when the relative error in Chi-square is less than the setting value
Input number range: Minimum 2.220446E-16 to Maximum 0.01
If you input small number, the searching result is more accurate but it takes longer time.

93. For Genetic Analysis

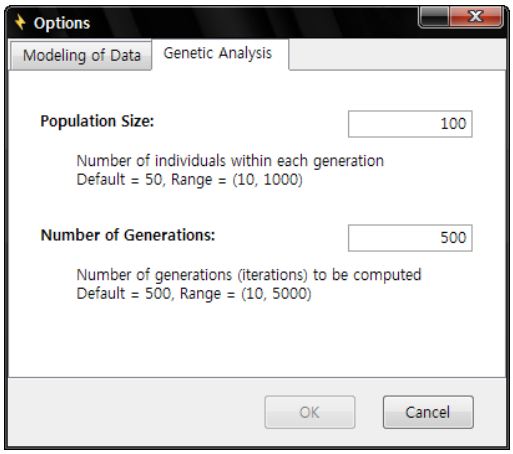


Figure 195. Genetic analysis for searching criteira

If you select genetic analysis initial guessing for automatic model searching, you can set limit criteria for ZMAN to determine the model.

a) Population size: Default (100)

Number of individuals within each generation
Input number range: Minimum 10 to Maximum 1000

b) Number of Generations: Default(500)

Number of generations(iterations) to be computed
Input number range: Minimum 10 to Maximum 5000

C. Searching process

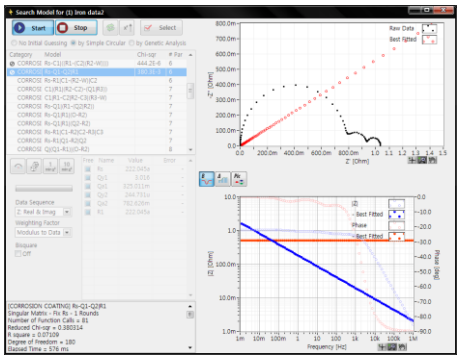


Figure 196. Searching process

94. Start searching

During searching process, searching engine is trying to find proper model and displaying spectra matching process graphically in real time. You can see the tracing process in Nyquist plot, Bode plot and error diagram.

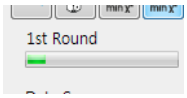


Figure 197. Process bar

If the process bar is working, The software is running (complicated model may take long time).

95. Stop searching

If you need to stop during searching, click 

button.
If fitting process is complicated with multiple parameter model, it could not be stopped promptly. In this case stop button will be changed 

button.
After calculation, searching process will be stopped.

96. Change searching condition

If you stopped or finished searching process, you can change searching process by clicking  button then searching condition menu will appear. You can restart searching with new condition.

D. Searching Result

When searching process finished, you can see the model list on left upper side. List will be arranged by chi square value.

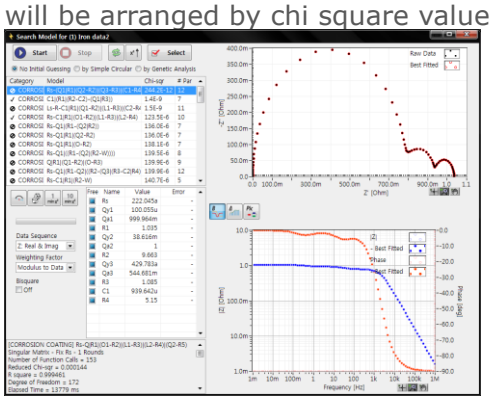


Figure 198. Searching result

97. Extensive fitting

If you did not set Bi-square option when you search, you can use it at this moment to find best model.

To do this, check on Bi-square option and click 

"minimize 1 round" button. If fitting process look to need further process by tracing trend, you can click 

"minimize 10 round" button. This button will do 10 times repetition of "Minimize 1round".

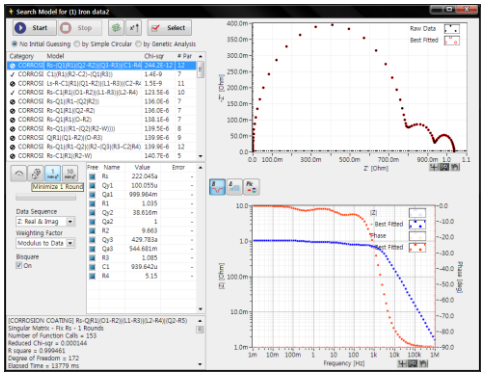


Figure 199. Bi-square fitting

If the result(chi-square value) order is different from previous, you can rearrange the order by clicking  button.

98. Fitting by parameter range

You can check the fitting result and if you want to change parameter range, you can change all parameter range by clicking right button of mouse at "Free" character's area then popup menu will appear.

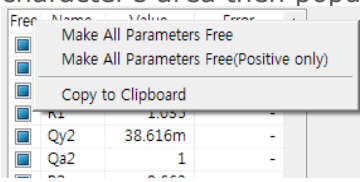


Figure 200. All parameter range selection

You can change parameter range by clicking parameter range marker.
Parameter range setting markers are

 : Fix

 : Positive value only free

 : Negative/Positive value free

99. Initial guessing/fitting

From the result, you can try to fitting for each model on result list.
Generally do not use initial guessing on result.

 : Simple circular method

 : Genetic analysis method

100. Repeat searching model

Based on searching result, you can search the result model again in chi square order.
In this case, select "no initial guessing" and click start button

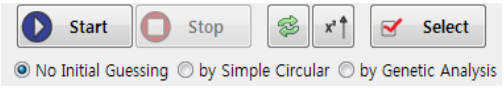


Figure 201. Repeat searching model

101. Singular matrix result

At category display region, if the result is singular matrix error, ⊘ tag will be displayed. If the result is successful, ✓tag will be displayed.
If a singular matrix results, a diagnostic message will be displayed.

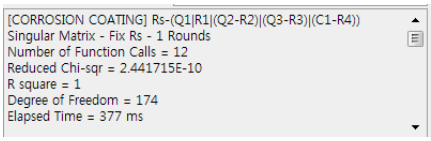


Figure 202. Fitting process report

Based on the fitting process report, fix the indicated parameter by clicking parameter range setting marker to ☐ status and try to fit again.

102. Ending Search process

If you find a suitable model by automatic model searching function, you must click 

button.

Chapter 9 Impedance Data Plot

A. How to plot data in a graph.

103. Select a data set

Select a data set from a data series or individual data files from Project (Section "C"). This will be shown in a graph.

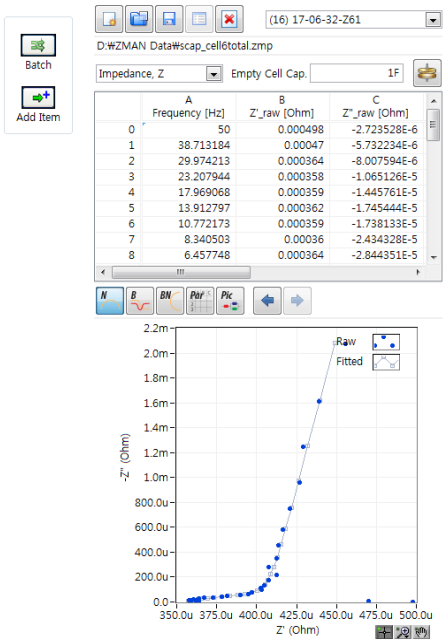


Figure 203. Project file data preview

104. Select Plot Option

Select one among the following three options from Plot menu. If you want a parameter plot, skip this step.

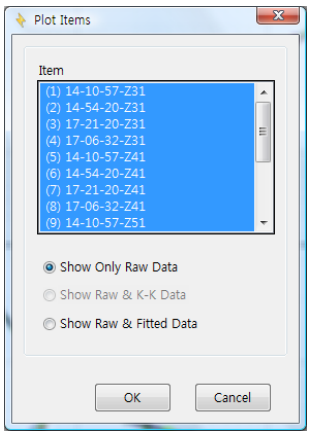


Figure 204. Plot display selection for 2D plots (except parameter plot)

- Show only Raw Data
- Show Raw and K-K

- Show Raw and Fitted-Data

105. Plot formats

Available graph types are listed in the following table.

	Type	x	y	z
2D	Nyquist	Real part(Z')	-Z"	
		Y'	Y"	
	Bode	f	y1 | y2: |Z| | Φ_Z	
			Z', -Z", |Z|,Φ_Z	
			Y', Y", |Y|, Φ_Y	
	Parameter	CtrlVar1..3	P_1..P_n	
3D	Nyquist	Z'	No, f, CtrlVar1..3	-Z"
		Y'		Y"
	Bode	f	#, CtrlVar1..3	Z', -Z", |Z|,Φ_Z
				Y', Y", |Y|, Φ_Y
	Parameters	Not available		

Where f is frequency, $Z = Z' + jZ'' = |Z|e^{j\Phi_Z}$, and $Y = \frac{1}{Z} = Y' + jY'' = |Y|e^{j\Phi_Y}$.

a) 2D Nyquist Plot

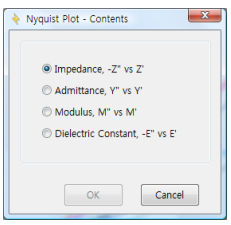


Figure 205. 2D Nyquist plot's display selection

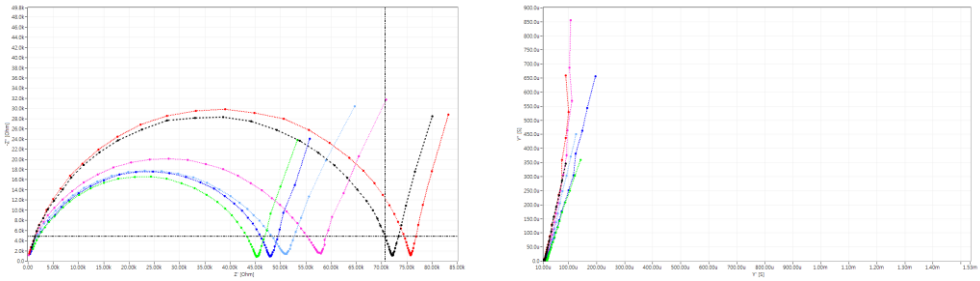


Figure 206. Impedance & Admittance plots

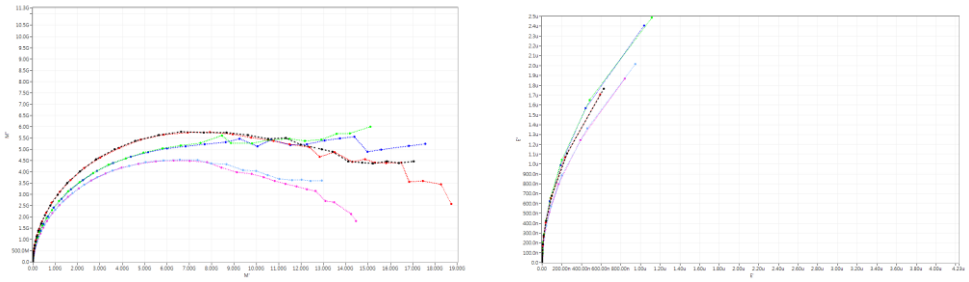


Figure 207. Modulus & Dielectric constant plots

b) 2D Bode Plot

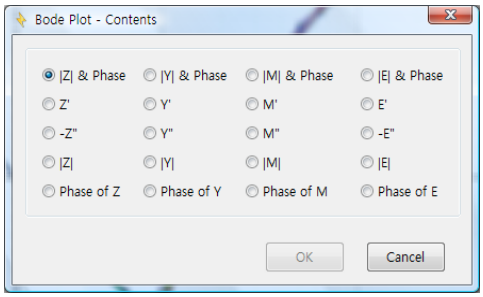
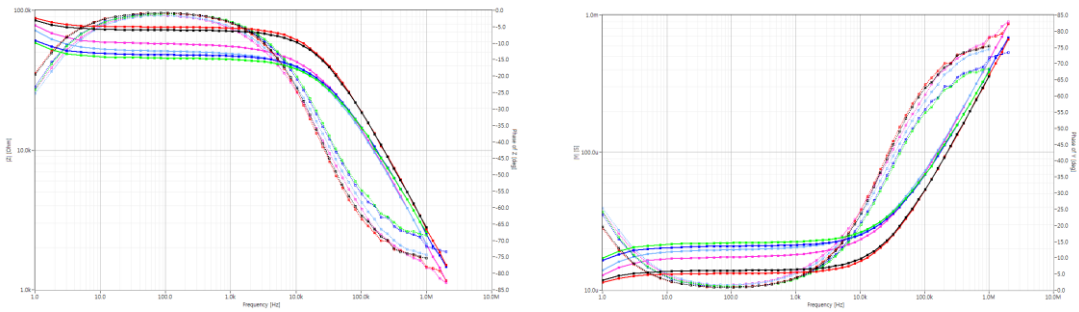


Figure 208. 2D Bode plot's display selection



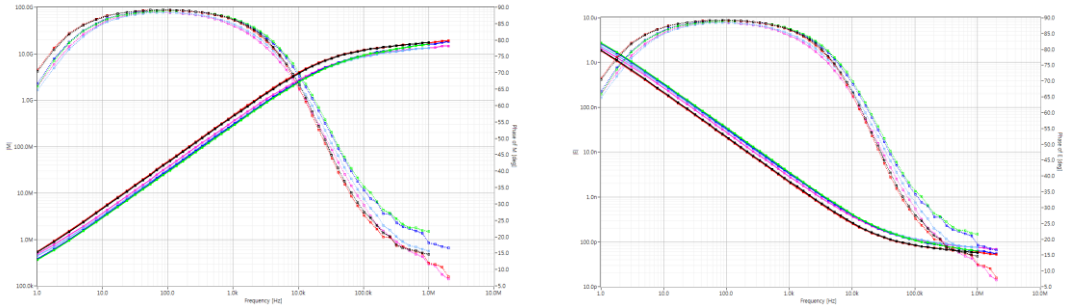


Figure 209. |Z|& phase, |Y| & phase, |M| & phase, |E| & phase plots

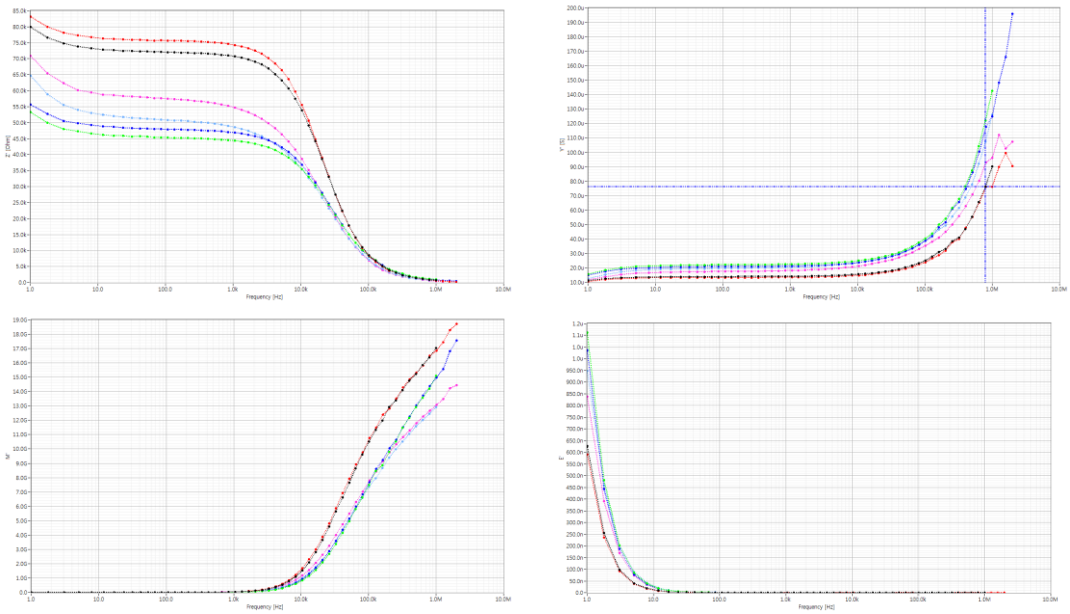
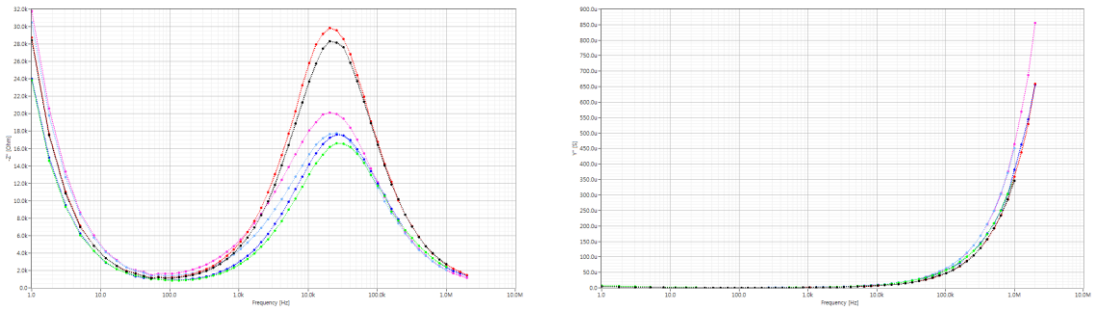


Figure 210. Z',Y',M',E' vs. Frequency plots



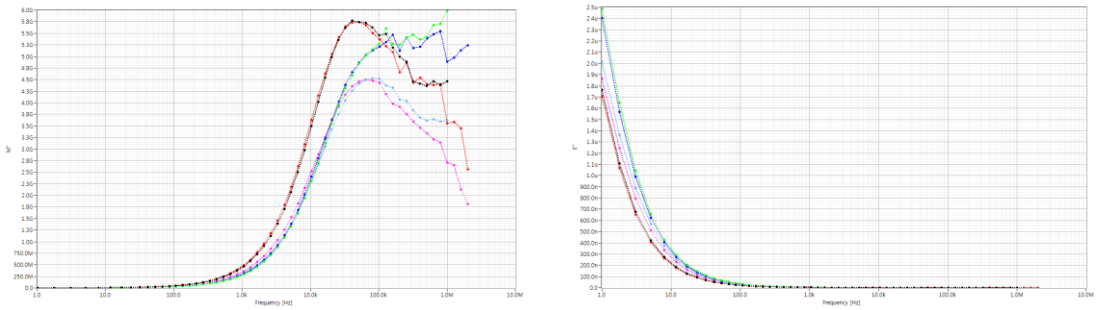


Figure 211. Z'',Y'',M'',E'' vs. Frequency plots

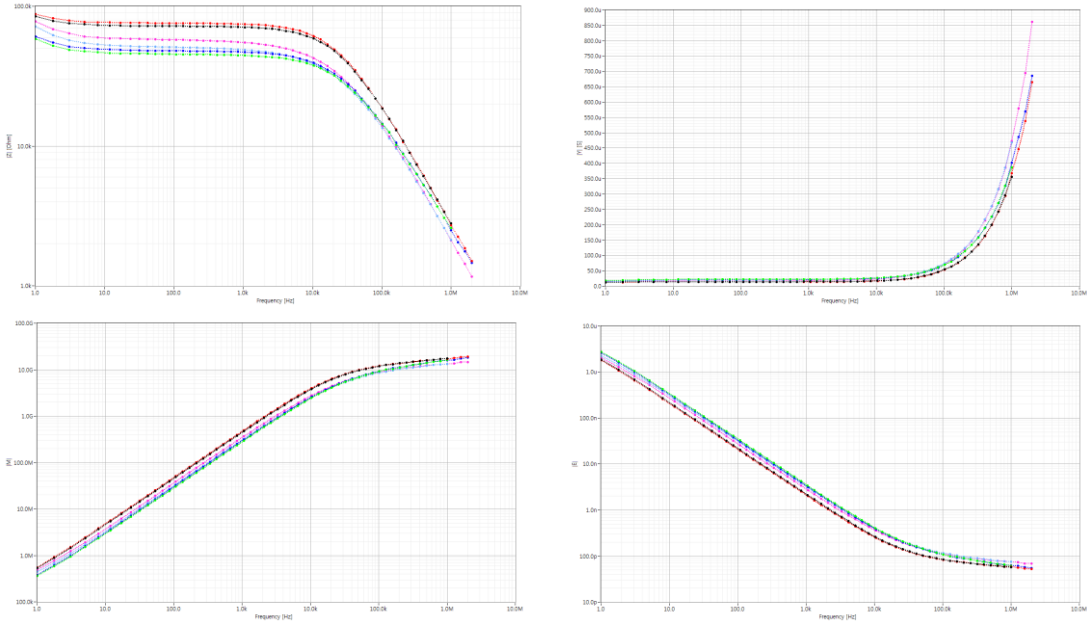
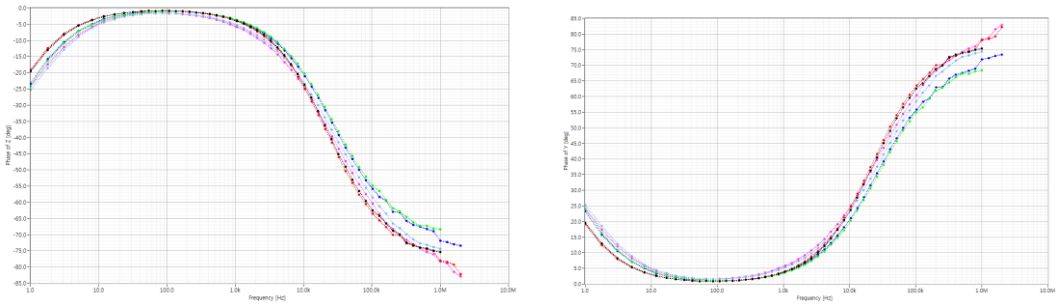


Figure 212. |Z|,|Y|,|M|,|E| vs. Frequency plots



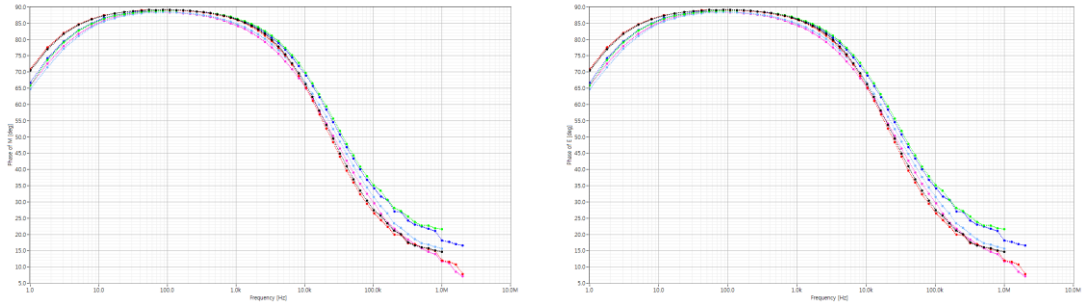


Figure 213. Phase of Z',Y',M',E' vs. Frequency plots

c) Parameter Plot

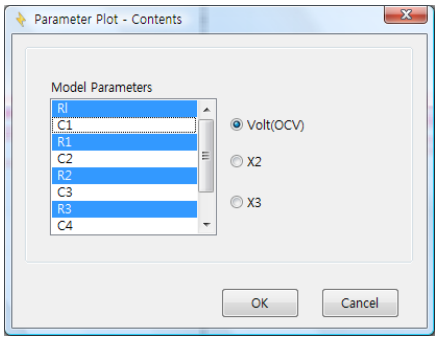


Figure 214. 2D Parameter plot's parameter selection

d) 3D Nyquist plot

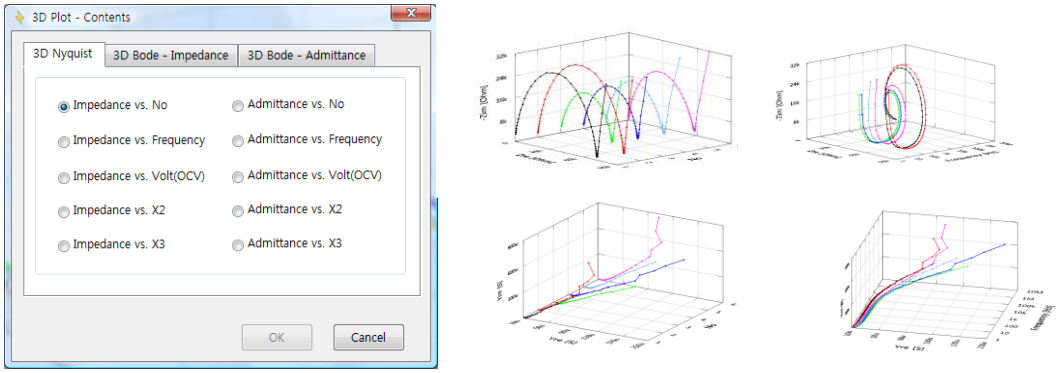


Figure 215. 3D Graph > 3D Nyquist

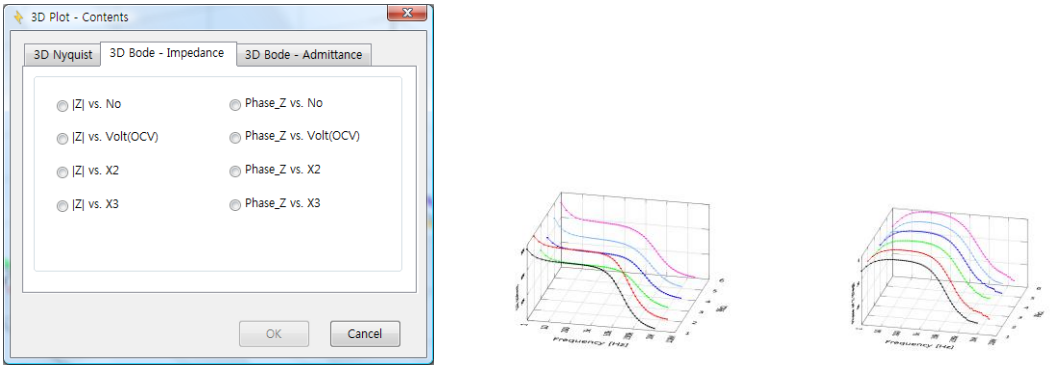


Figure 216. 3D Graph > 3D Bode –Impedance

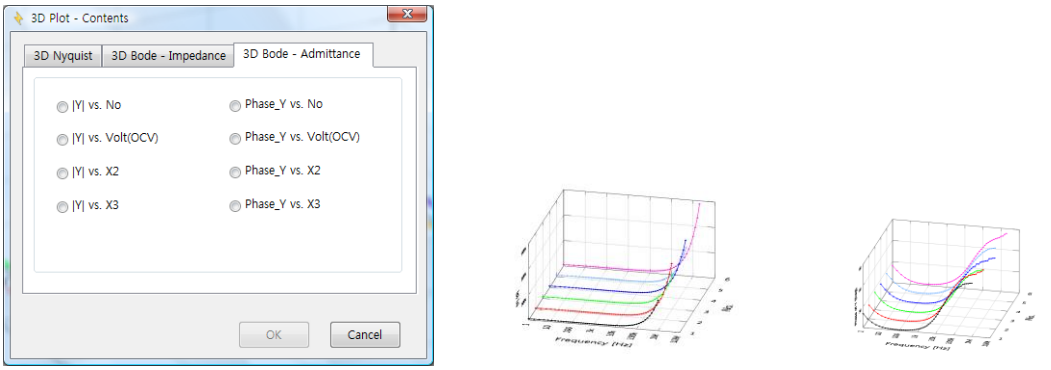


Figure 217. 3D Bode-Admittance

B. How to Format Axis Scales

106. Select 2D or 3D Plot settings

Select **2D Plot Settings** or **3D Plot Settings** from the Plot menu. **Y2 axis** is available only in 2D-Bode Plot.

107. Configure Axis/Scale properties

Configure the axis scale properties. Modifications are immediately reflected in the graph.

- Use the **Format** and **Precision** to format Tick Label on an axis.
- Click **Major Grid** and **Minor Grid** Box to change color of major and minor grid color, respectively. "T" means transparency.
- Make **Auto scale** ON to automatically adjust the scale.
- Make **Loose Fit** ON to round the end markers to a multiple of the increment used for the scale.
- Make **Flip Axis** ON to reverse min and max positions on the scale.
- Change **Logarithmic** ON/OFF for logarithmic/Linear scale mapping mode.
- Make **Show Cursor** ON/OFF to show/hide cursor on the graph.
- Make **Show Graph Palette** ON/OFF to show/hide graph palette on the graph.

Click **Apply** to apply the modification to the graph.

108. Setting

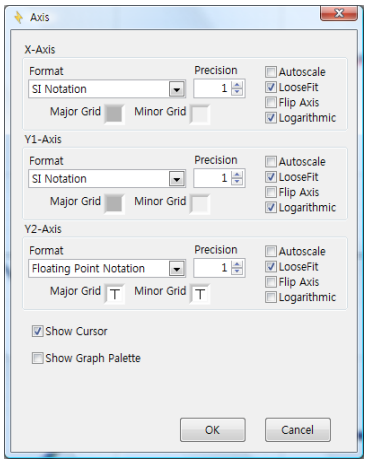


Figure 218. 2D Setting

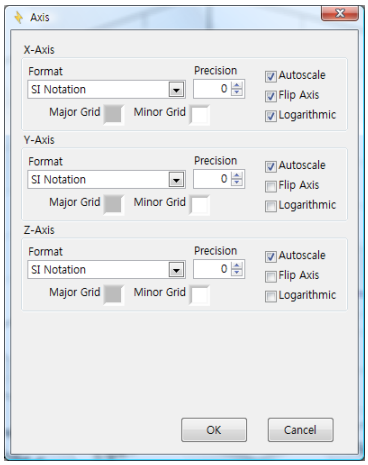


Figure 219. 3D Setting

Chapter 10 Graph

A. 2D Graph common functions

109. Legend

You can display Legend on graphic region by clicking  button on graphic tool bar.

File name change on graph(Just displaying)

If you click Legend button  you can see legend right upper side and you can change the name by clicking on the name.

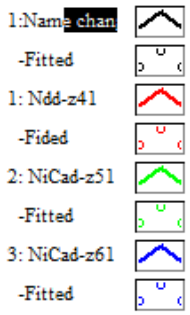


Figure 220. Legend

Click on file name and change it.

110. Side function of Graph

You can use this function only when Legend is ON.
Move the cursor to Legend and click on box right side of file name then pop up menu will appear.

a) Common plot

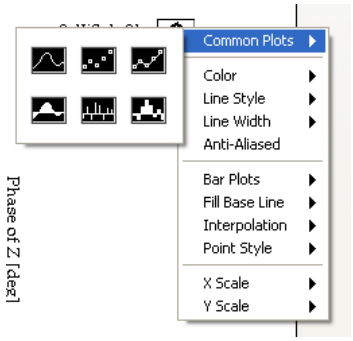


Figure 221. Legend menu

b) Line color

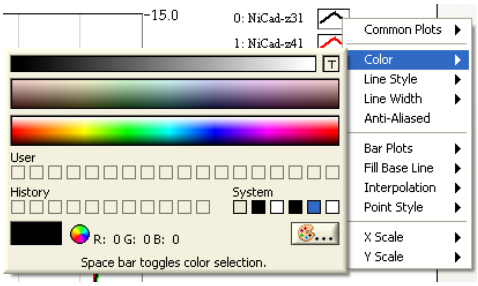


Figure 222. Line color setting

c) Line style

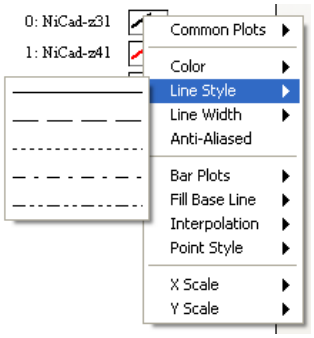


Figure 223. Line style setting

d) Line width

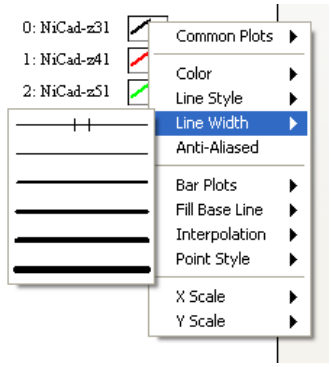


Figure 224. Line width setting

e) Bar plot

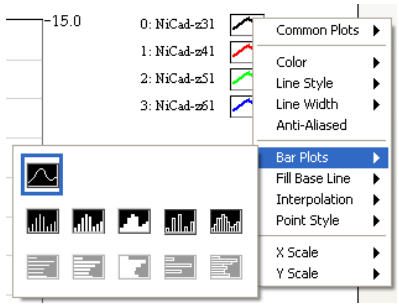


Figure 225. Bar plot setting

f) Interpolation

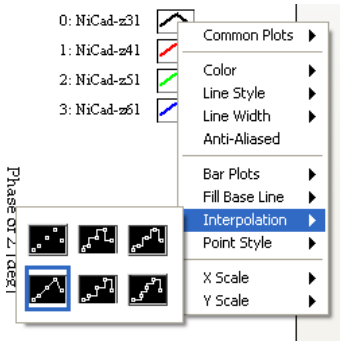


Figure 226. Interpolartion setting

g) Point Style

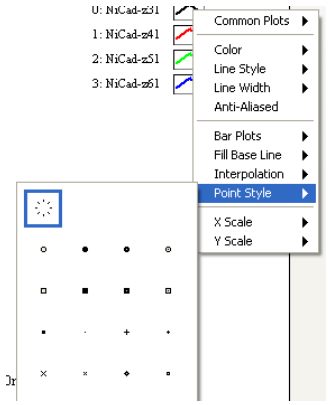


Figure 227. Point style selection

111. Rescale to show all

This function will redraw the graph to initial scale by clicking  button on graphic tool bar.

112. Cursor Mode

Cursor On/Off: You can make cursor mode on by clicking  button on graphic tool bar. If it is enable, you can see cross hair type cursor.
If you click on cross hair cursor location, you can see the cursor value display at near by cursor point.

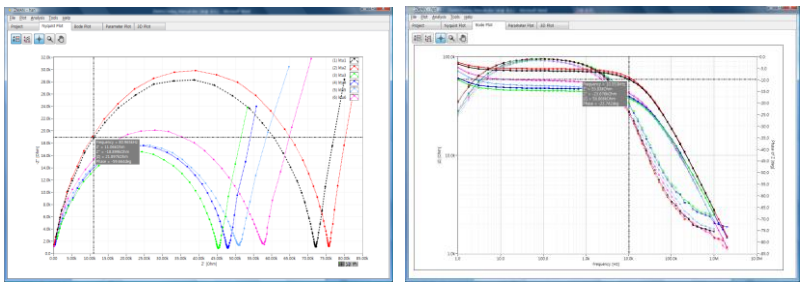


Figure 228. Cursor data display

Cursor will be displayed as cross hair. You can move the cursor position with your mouse or keyboard left/right direction key. Cross hair cursor's color will be changed by file's color. By keyboard up/down direction key, you can select data file which were overlaid.

When cursor mode is activated (on), 3 menu will be activated.

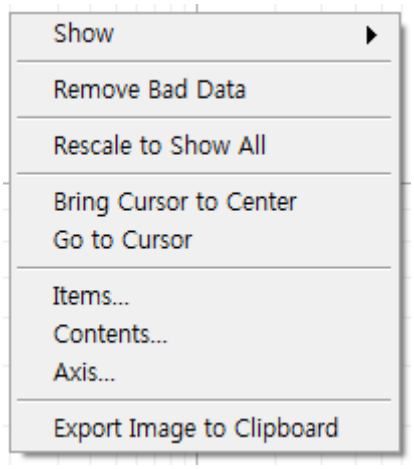


Figure 229. Pop up menu on 2D graph

a) Remove Bad data; You can delete bad data on cursor located.

You must check on cursor for this function. Select bad data using cursor function and click "Remove bad data"

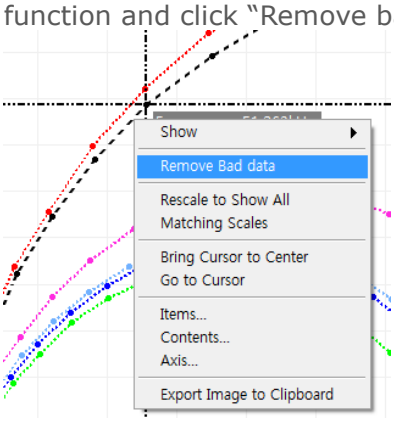


Figure 230. Remove bad data

b) Bring Cursor to Center:

If you check on this function, cursor will be located on center point of zoomed area.

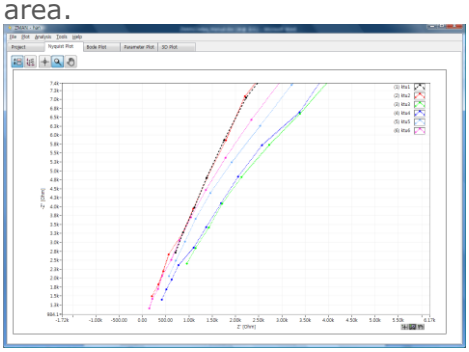


Figure 231. Zoom up display

If you click cursor button  but cursor was not displayed on the screen then select “Bring cursor to center”.
The cursor will be located near by center position.

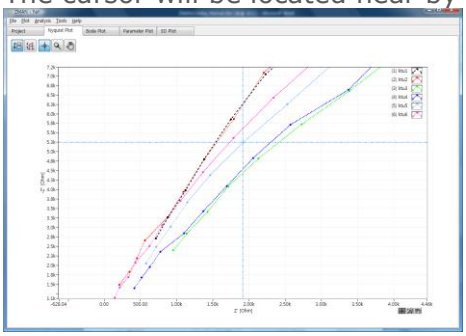


Figure 232. “Bring cursor to center” function

Please note that the data should be located in center position. You can use move button  to move the display position.

113. Zoom

For zooming Click  button and drag the area

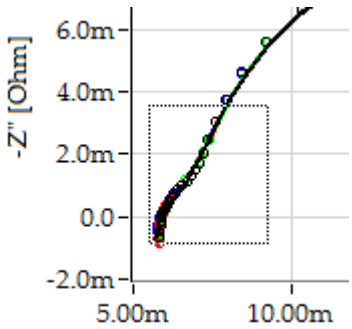


Figure 233. Before Zoom up

Mouse selecting an area to zoom up

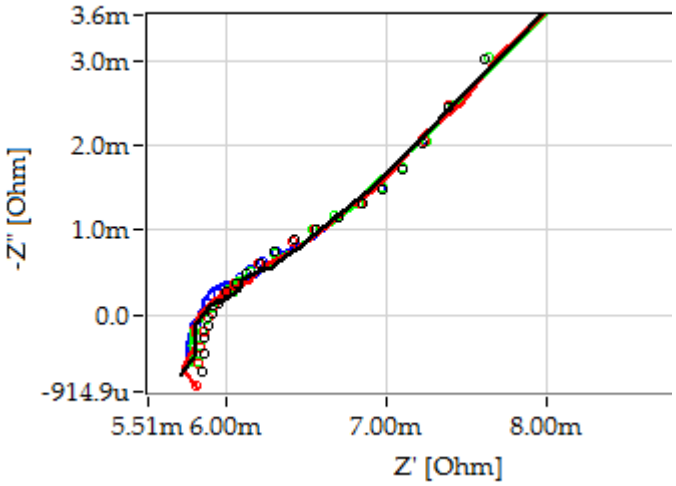


Figure 234. After zoom up

114. Axis scale

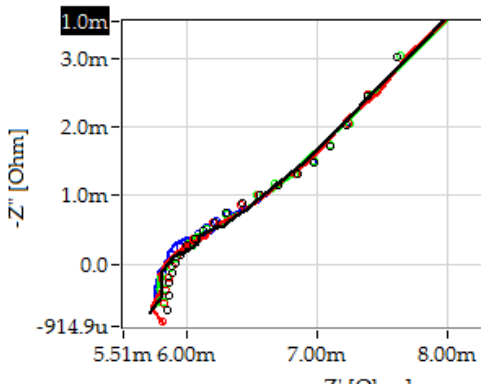


Figure 235. Before Max value change

Change maximum axis value by clicking on a value

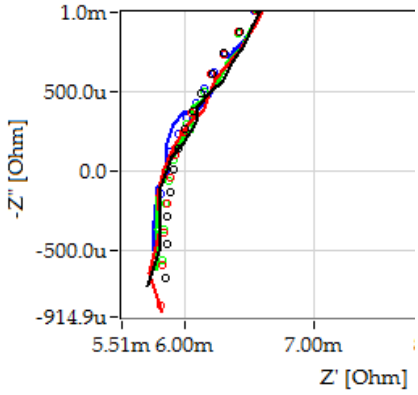


Figure 236. After max value change

B. Graph internal function for Bode & Nyquist plot

Move the cursor inside the graph and click right button, the following sub menu will then appear.

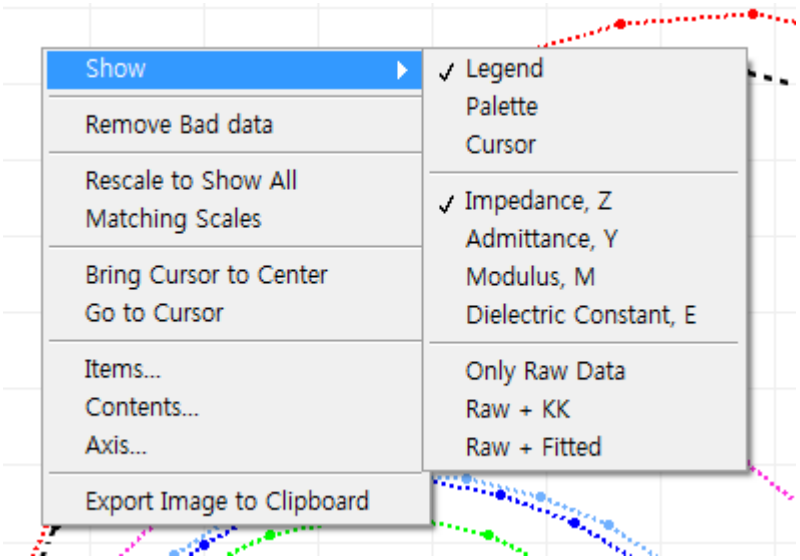


Figure 237. Graph function menu

115. Show

a) Legend On/Off: If you check on Legend you can see Legend on the graph you can click 

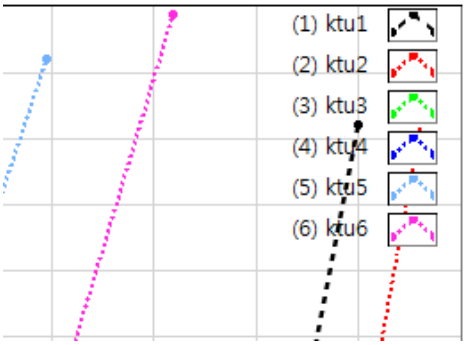


Figure 238. With legend

b) Palette on/off

You can enable/disable the palette function. 
Graph Pallet

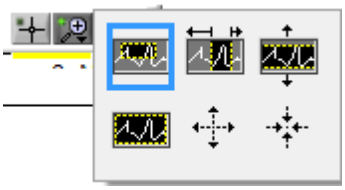


Figure 239. Graph pallet

c) Cursor On/Off

Refer to the above Cursor mode

If You can select Impedance, Admittance, Modulus or Dielectric constant

d) Impedance

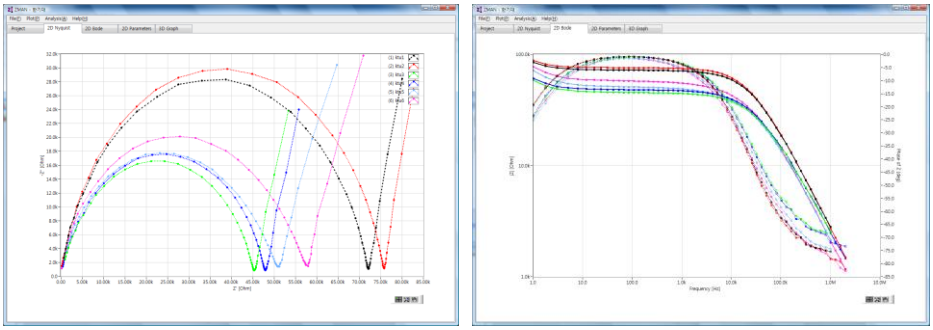


Figure 240. Impedance

e) Admittance

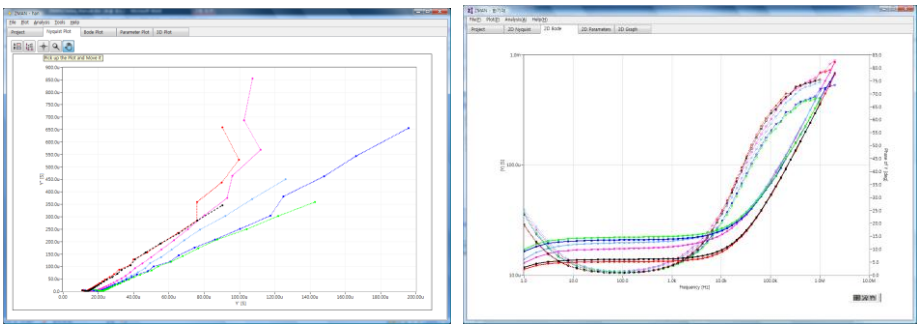


Figure 241. Admittance

f) Modulus

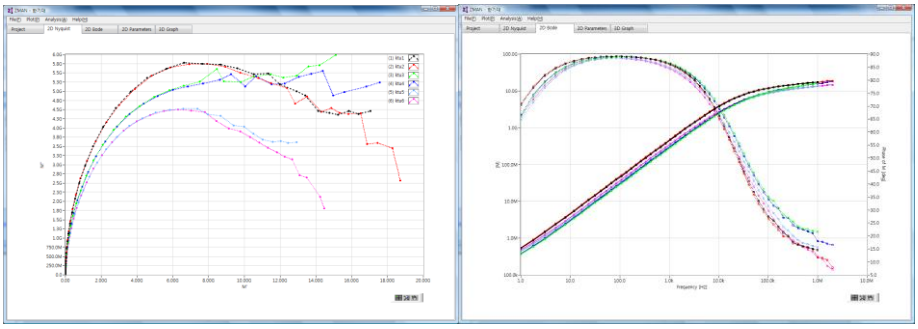


Figure 242. Modulus

g) Dielectric Constant

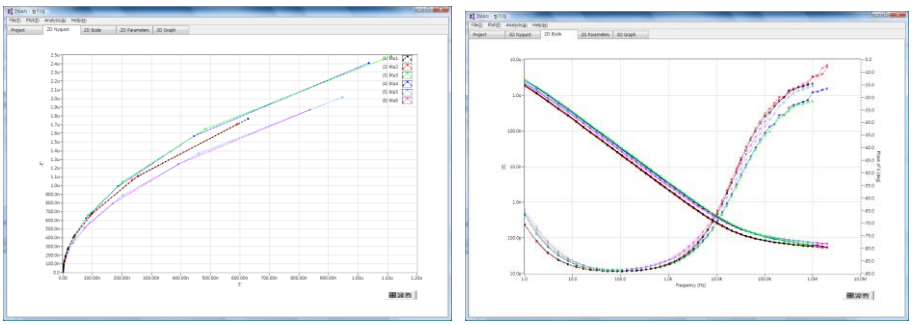


Figure 243. Dielectric Constant

h) Only Raw data

Plot with raw data only

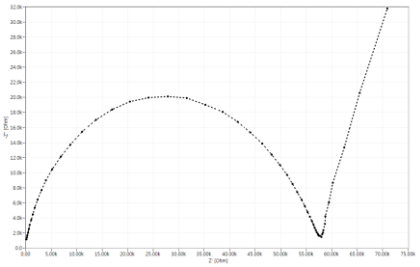
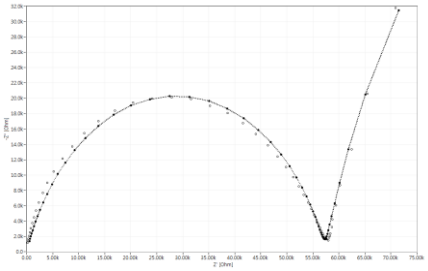


Figure 244. Raw data only

i) Raw+Fitted

Plot with raw data and fitted data together.



116. Remove Bad data: You can delete bad data.

Refer to the above cursor mode

117. Rescale to show all

Initiate graph scale.

118. Matching Scale (Only for Nyquist Plot)

The Nyquist plot will be displayed with the same scale for X axis and Y axis.

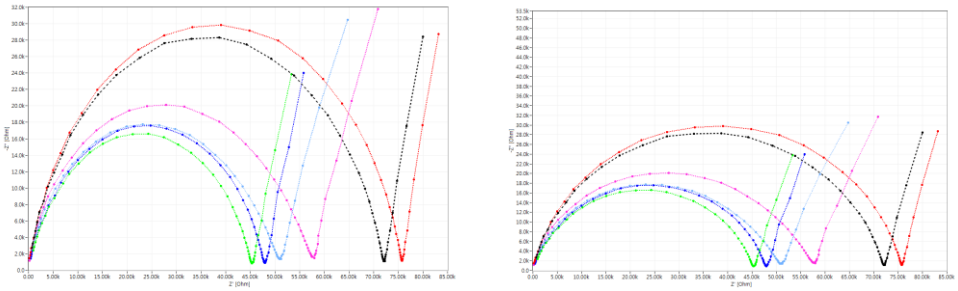


Figure 245. Show all scale(Left) & Matching scale(Right)

119. Item

You can select file to plot and select raw data or raw + fitted data or Raw+K-K Data.

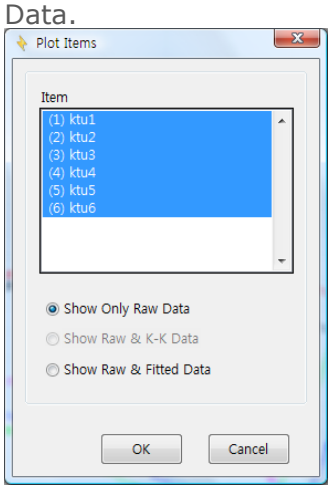


Figure 246. Plot item selection

120. Contents

You can select plot type

a) Nyquist plot

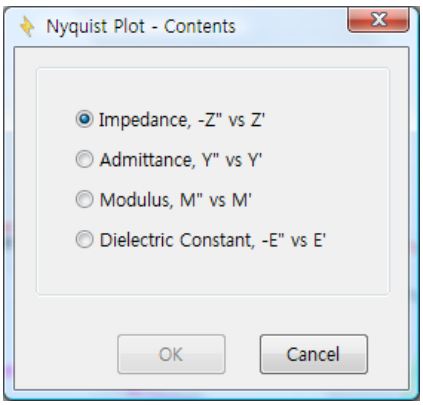


Figure 247. Nyquist plot contents

b) Bode Plot

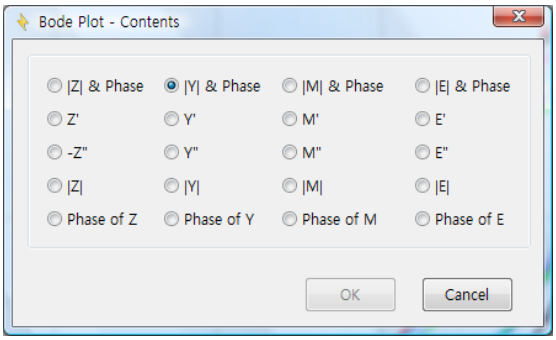


Figure 248. Bode plot contents

121. Axis

You can set graph properties.

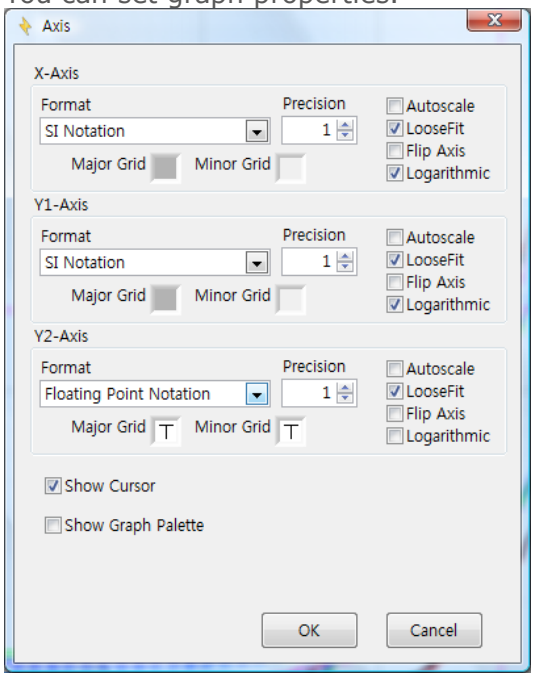


Figure 249. 2D graph setting

122. Export Image to Clipboard

You can use image in other program Using Windows Paste(Ctrl+V) function

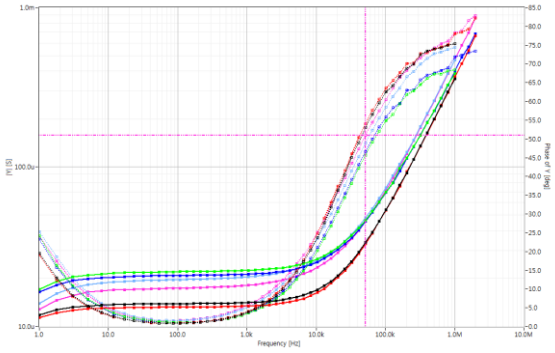


Figure 250. Paste result

C. Graph internal function for Parameter plot

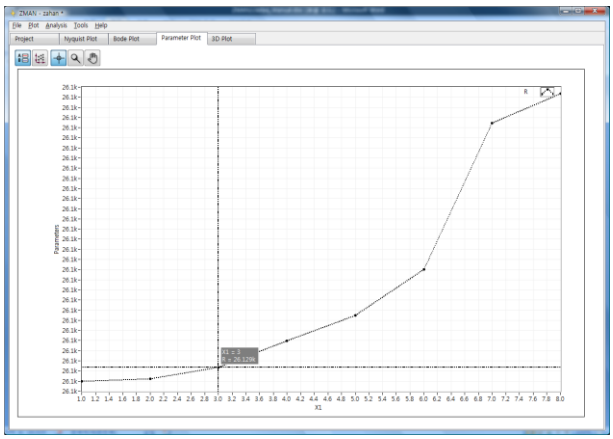


Figure 251. Parameter plot

Move the cursor to inside the graph and click right button, the following sub menu will appear.

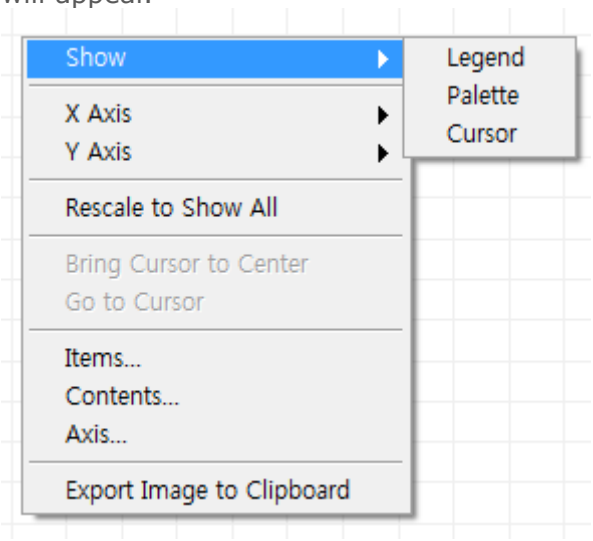


Figure 252. Parameter plot menu

123. Show

a) Legend On/Off:

If you check on Legend you can see Legend on the graph

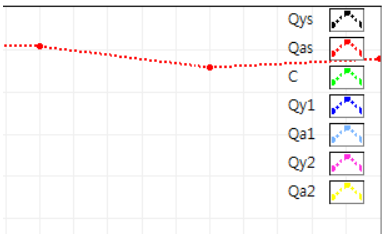


Figure 253. With legend

b) Palette On/Off
c) Cursor On/Off

124. X axis setting

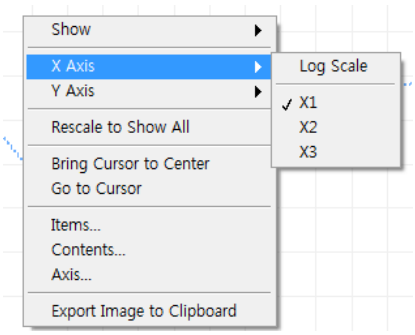


Figure 254. X axis setting

X1, X2, X3 will be replaced if you input name for these parameters.

125. Y axis setting

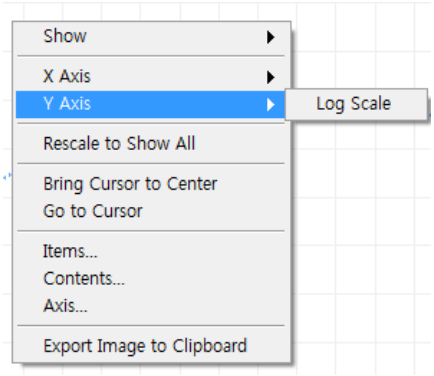


Figure 255. Y axis setting

126. Contents

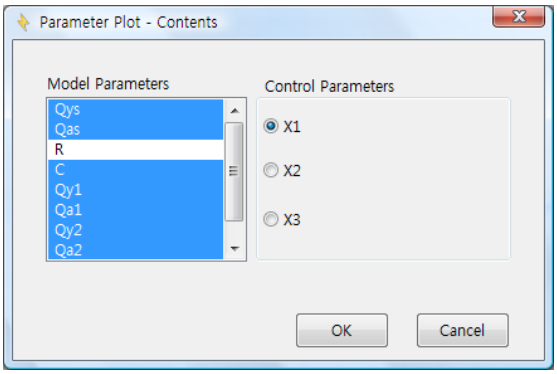


Figure 256. Parameter plot contents

- Other functions are referred to above 2D plot

D. 3D Plot

3D plot can be used for multiple EIS data display or Multiple axis plots.

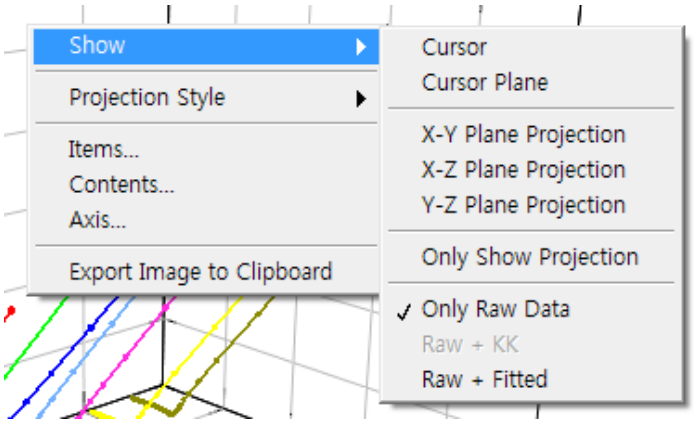


Figure 257. 3D graph Internal function

127. Cursor

a) Cursor On/Off

You can select Cusor On/Off on Show option or click  button at left upper side.

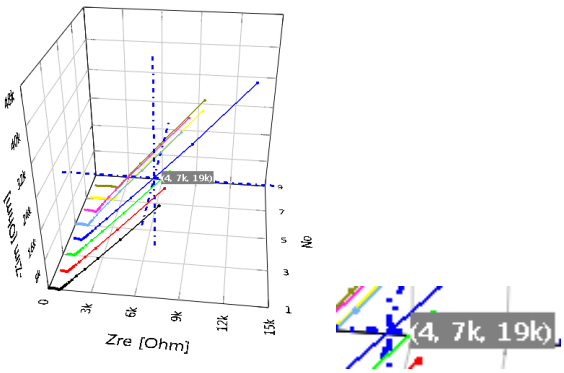


Figure 258. Cusor On at 3D graph Nyquist plot per parameter

With Cursor On, there is X, Y, Z coordinate value with data color. Cross hair cursor can be moved to other point or other data file by mouse draggin. Up and downward key on keyboard can be used for moving data on same data file.

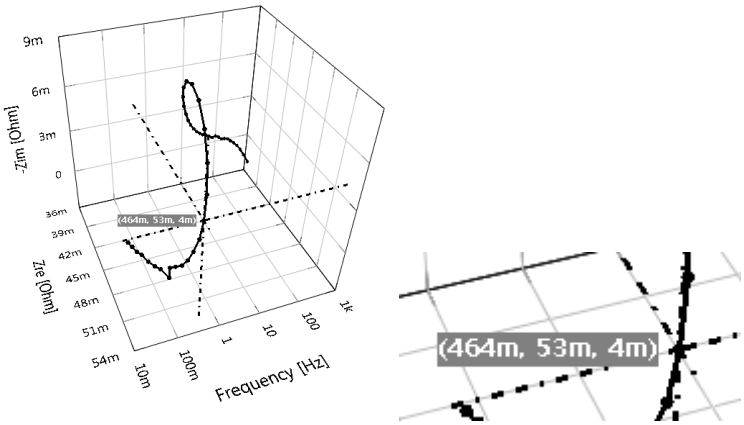


Figure 259. Cursor on at 3D graph Nyquist plot per frequency

b) Cursor plane

Cursor plane can be visible by selecting cursor plane on Show option.

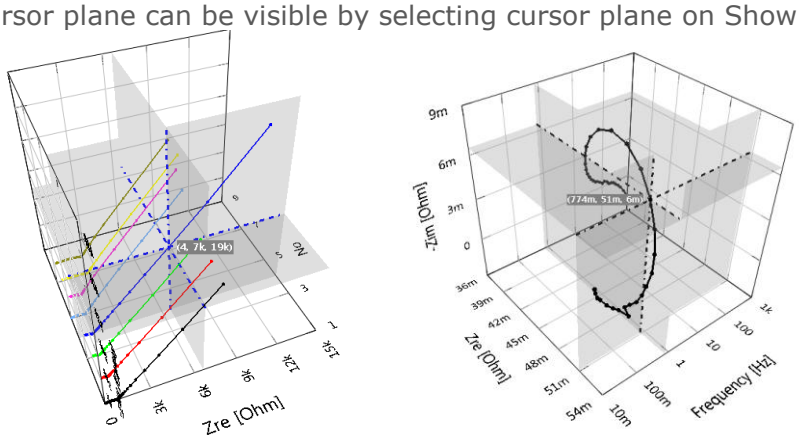


Figure 260. 3D plot with cursor plane

128. Plane Projection

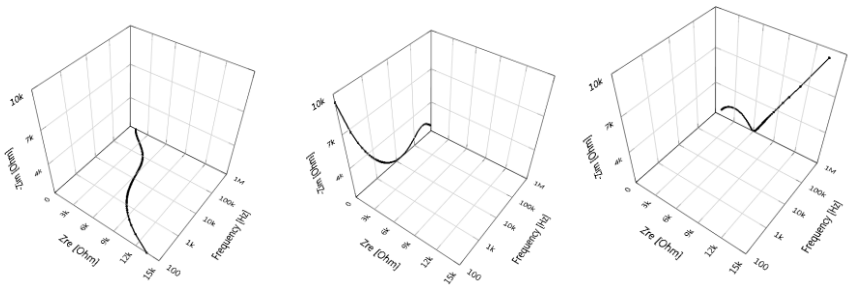


Figure 261. XY , XZ, YZ plane projection

You can select plane projection in Show option.

129. Projection Style

There is two type depending on projection style (orthographic or perspective)

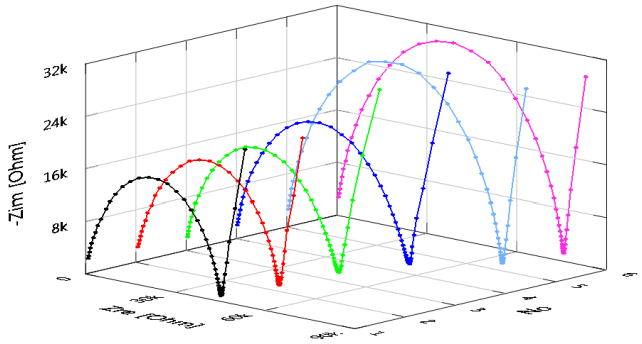


Figure 262. 3D nyquist plot (orthographic style)

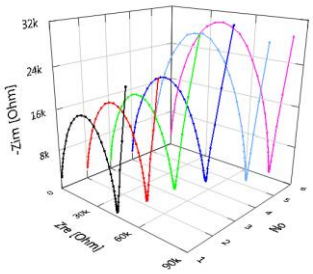


Figure 263. 3D Nyquist plot(perspective style)

Version 2.2 does not provide surface plot which have provided in previous versions.

You can change the view angle by dragging on the graph

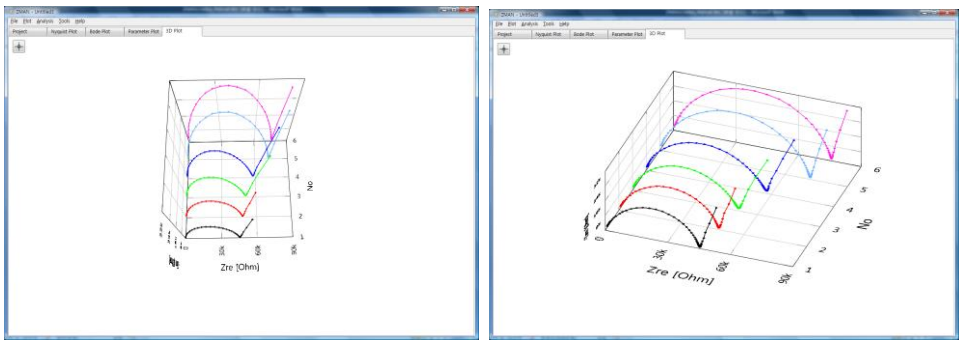


Figure 264. View angle change(Left: orthographic, Right perspective)

130. Plot Item

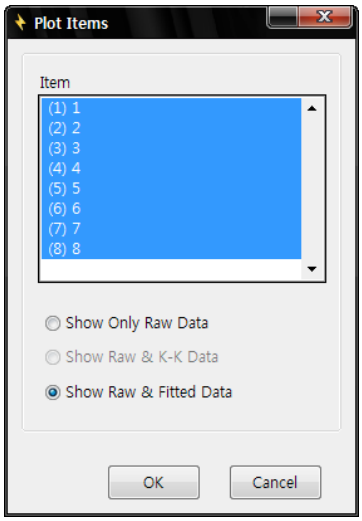


Figure 265. 3D graph plot item

- You can select file(s) to plot and select "Show Only Raw Data" or Show Raw & K-K Data" or "Show Raw & Fitted Data"
- K-K data and Fitted Data selection is only enable status after analysis of fitting or K-K
- If you select "Show Only Raw Data", then Raw data will be plot as solid line with dot. But if you select "Show Raw & Fitted Data", then Fitted data is solid line and raw data is dot

131. Contents

You can select one of 3D plot in followings.

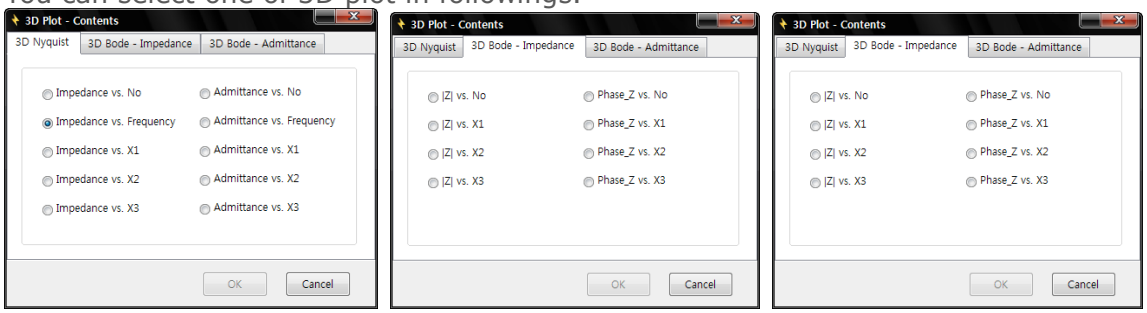


Figure 266. 3D Plot contents

E. Parameter Plot

After fitting result, you can get parameter plot with fitting result

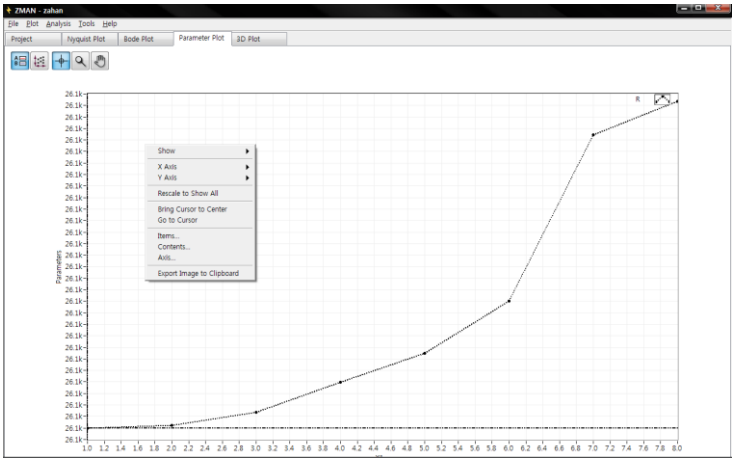


Figure 267. Parameter plot

132. Parameter to display

You can select parameter(s) to display on plot by selecting contents in the pop up menu.

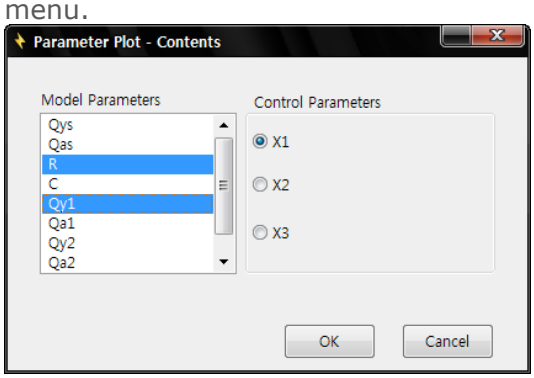


Figure 268. Parameter to display

Multiple parameters can be selected by cliking ctrl+click or shift+click

133. File select

You can select file(s) to display parameter(s) by selcting items in the pop up menu.

134. Axis

Parameter plot can select X1, X2, X3 control value as X axis. X & Y axis can be displayed as linear scale or log scale.