ModuLab XM

Materials Test System

USER GUIDE

Advanced Measurement Technology, Inc.

AMETEK®

ORTEC Princeton Applied Research solartron analytical Signal Recovery SUNPOWER

CE UKCA

DECLARATION OF CONFORMITY

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Model(s): MODULAB XM MTS

Advanced Measurement Technology (AMT) declares under our sole responsibility that the Model(s) to which this declaration relates is in conformity with the following standard(s) or other normative document(s), in accordance with the provisions of

73/23/EEC Low Voltage Equipment Directive, amended by 93/68/EEC

89/336/EEC Electromagnetic Compatibility Directive, amended by 92/31/EEC & 93/68/EEC

STANDARDS:

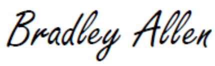
BS EN61326:1997 Electrical equipment for measurement control and laboratory use -EMC requirements; including amendments A1:1998 and A2:2001.

BS EN61010-1:2001 Safety requirements for electrical equipment for measurement, control and laboratory use.

Type of Equipment: Materials Test System

Year of Manufacture: 2022

Declaration:

Dan Jones	**Bradley Allen**
AMETEK AMT Quality Assurance	**AMETEK AMT DVP of Engineering**
	
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Spectrum House, 1 Millars Business Centre **Fishponds Close** **Wokingham, Berkshire RG41 2TZ,** **United Kingdom**	**30 NOV 2022**
Place of issuance	**Date of issuance**

ACCORDINGLY, CONFORMITY MARKINGS HAVE BEEN APPLIED TO THIS PRODUCT

Importer: ______________________________

GENERAL SAFETY PRECAUTIONS

The equipment described in this manual has been designed in accordance with EN61010 "Safety requirements for electrical equipment for measurement, control and laboratory use", and has been supplied in a safe condition. To avoid injury to an operator or service technician the safety precautions given below, and throughout the manual, must be strictly adhered to, whenever the equipment is operated, serviced or repaired. For specific safety details, please refer to the relevant sections within the manual.

The equipment is intended solely for electronic measurement and should be used for no other purpose. The equipment protection may be impaired if it is not operated in a manner as specified by Solartron and detailed in this document. Solartron accept no responsibility for accidents or damage resulting from any failure to comply with these precautions.

GROUNDING

To minimise the hazard of electrical shock, it is essential that the equipment be connected to a protective ground through the AC supply cable. The continuity of the ground connection should be checked periodically.

AC SUPPLY VOLTAGE

Never operate the equipment from a line voltage or frequency in excess of that specified. Otherwise, the insulation of internal components may break down and cause excessive leakage currents. The equipment is to be used with an IEC 60799 compliant mains supply cord, rated for the correct voltage and power rating as detailed on the rear panel.

FUSES

Before switching on the equipment check that the fuses accessible from the exterior of the equipment are of the correct rating. The rating of the AC line fuse must be in accordance with the voltage of the AC supply.

T10A H 250V (100-120V mains supply)

T5A H 250V (220-240V mains supply)

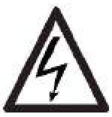
Should any fuse continually blow, do not insert a fuse of a higher rating. Switch the equipment off, clearly label it "unserviceable" and inform a service technician.

EXPLOSIVE ATMOSPHERES

You must NEVER OPERATE the equipment, or any sensors connected to the equipment, in a potentially explosive atmosphere. The equipment is NOT designed for use in these conditions and could possibly cause an explosion.

SAFETY SYMBOL

For the guidance and protection of the user, the following safety symbol appears on the equipment:

Symbol	***Meaning***
	General safety hazard. Refer to the operating manual for detailed instructions.
	Electrical safety hazard. This symbol may appear alongside the general safety hazard symbol, together with a voltage.

General Safety Precautions (*continued from previous page*)

Symbol	*Meaning*
	Safety hazard involving heavy weights. A numerical value for the amount of weight may appear alongside this symbol. Take care when handling and carrying. Follow the manufacturer's instructions, and ask for assistance if necessary.

NOTES, CAUTIONS AND WARNINGS

For the guidance and protection of the user, **Notes**, **Cautions** and **Warnings** appear throughout the manual. The significance of these is as follows:

NOTES	highlight important information for the reader's special attention.
CAUTIONS	guide the reader in avoiding damage to the equipment.
WARNINGS	guide the reader in avoiding a hazard that could cause injury or death.

AVOID UNSAFE EQUIPMENT

The equipment may be unsafe if any of the following statements apply:

- Equipment shows visible damage.
- Equipment has failed to perform an intended operation.
- Equipment has been stored in unfavourable conditions.
- Equipment has been subjected to severe physical stress.

If in any doubt as to the serviceability of the equipment, don't use it. Get it properly checked out by a qualified service technician.

LIVE CONDUCTORS

When the equipment is connected to its measurement inputs or supply, the opening of covers or removal of parts could expose live conductors. The equipment must be disconnected from all power and signal sources before it is opened for any adjustment, replacement, maintenance or repair. Adjustments, maintenance or repair must only be done by qualified personnel, who should refer to the relevant maintenance documentation.

EQUIPMENT MODIFICATION

To avoid introducing safety hazards, never install non-standard parts in the equipment, or make any unauthorised modification. To maintain safety, always return the equipment to your Solartron service provider for service and repair.

Text Conventions

The following text conventions are used in the ModuLab XM MTS documentation:

- Bold text is used for headings.
- Blue text is used for names and titles of features of the ModuLab XM hardware and software, when it is required that the user, at this point, should find these features on the system.
- Italic text is used for words and phrases that have a specific meaning within ModuLab XM, without being names or titles, for example *project*, *experiment* and *step*. Definitions of the italicised words and phrases are in the Glossary of Terms.
- Finger pointers are used for cross-references, for example:

  ☞ Chapter 8, Glossary of Terms.

Contents

1. The ModuLab® XM MTS System

1.1 SYSTEM OVERVIEW

The ModuLab® XM MTS Materials Test System is a highly versatile test system for measuring the characteristics of materials. A number of modules are combined into a single chassis, avoiding the need for stacking and wiring separate units. The modules are arranged in groups, known as *instrument groups,* each with a materials core module to enable DC measurements to be taken. Other modules in the group may provide AC functionality, or the measurement of high voltages, high impedances, or high power applications. Each *instrument group* in a chassis may perform a separate *experiment*, so there can be multiple *experiments* running simultaneously.

The modules in each group communicate with each other through the chassis backplane, and some of them are connected to an Ethernet hub, also mounted in the chassis, so that the system can be connected to an external PC running the ModuLab XM software for control and monitoring purposes.

The modules are mounted in slots in the chassis and can be removed and replaced as described in the Installation Guide, so that you can design and modify the system according to your requirements (although it is normally supplied with the modules assembled and configured for a specific purpose).

The ModuLab XM system is available with two different chassis sizes, depending on the number of modules required:

- The 4-slot chassis that takes up to four modules.
- The 8-slot chassis that takes up to eight modules.

☞ For more sophisticated test purposes, it is possible to build an expanded system by combining multiple ModuLab XM chasses through the Ethernet link, as described in the Installation Guide.

1.1.1 Instrument Groups

A group of modules in the chassis, consisting of a materials core module (XM MAT 1MHz) and a number of optional modules, is known as an *instrument group*.

There are a number of optional module types, and an *instrument group* can contain only one module of each type. These are the frequency response analyzer, high voltage module, femto ammeter, sample and reference module, and booster.

The optional modules, if fitted, must be installed in the correct slots in relation to the materials core module, as follows:

- If a frequency response analyzer is used, it must be in the adjacent slot to the left of the core module.

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- If a high voltage module, femto ammeter, sample and reference module or booster is used, they must be in adjacent slots to the right of the core module. If there is more than one module type, they must be arranged in the following order, from left to right:
    1. High voltage module;
    2. Femto ammeter module;
    3. Sample and reference module;
    4. Booster module, occupying two slots.

As long as these rules are observed, a core module and its companion modules may occupy any slots in the chassis, and if core modules are used on their own to take measurements, they can be installed in adjacent slots in any order.

Some examples of module arrangements are shown in Figure 1-1.

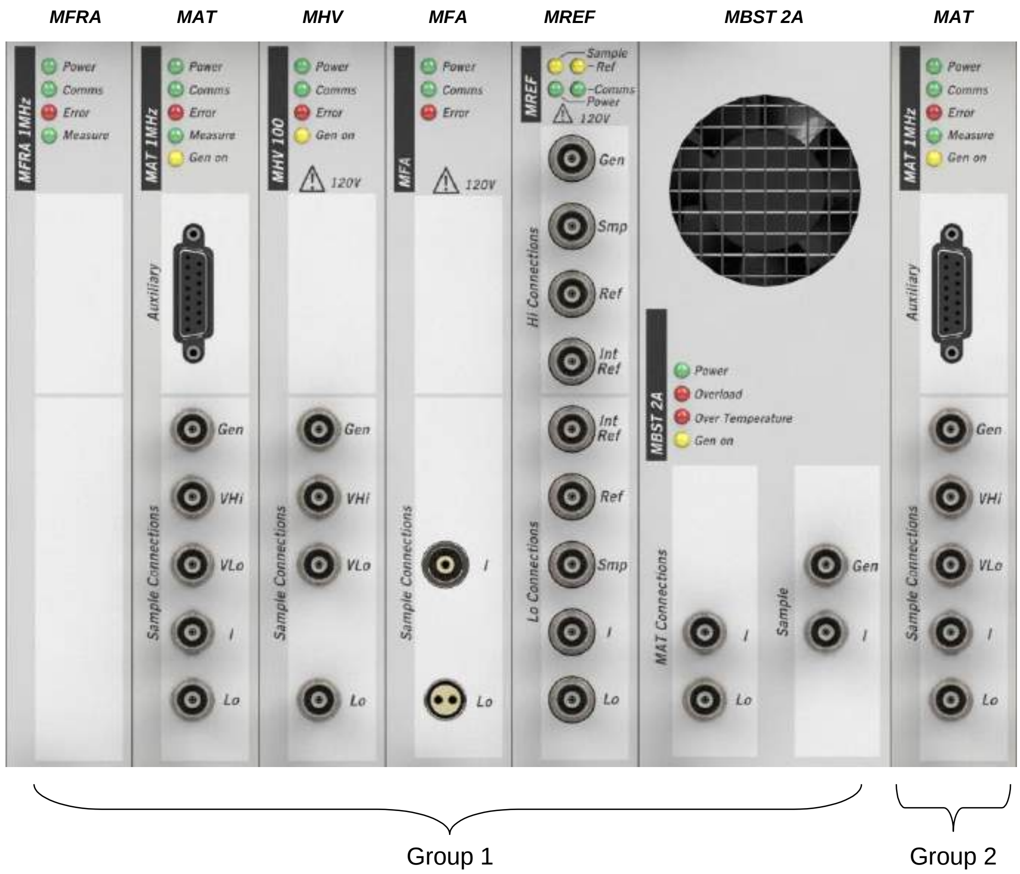


Figure 1-1 Example of instrument groups

In this example, the modules are arranged from left to right as follows:

- Group 1. A frequency response analyzer alongside a core module, followed by a high voltage module, femto ammeter, sample and reference module, and 2A booster, for DC and AC measurements at high voltage, and either at high impedance or high power. The femto ammeter and 2A booster can be installed within the same group, but cannot be used in the same *experiment*. Either the femto ammeter would be used for high impedance, or else the 2A booster for high power.
- Group 2. A core module by itself to perform DC measurements.

The ModuLab XM MTS system is normally supplied with all the modules installed, according to your requirements, so that it is only necessary to check that the modules are present and in the correct order.

1.1.2 Getting Started with ModuLab XM MTS

When you receive delivery of your ModuLab XM system, you will need to work through the manuals in the following order:

- The Getting Started manual gives a limited set of installation instructions, sufficient to connect the ModuLab XM chassis to a PC and run a simple DC *experiment* using a ready-made software configuration, and a test unit known as the Dielectric Reference Module to represent a material sample. This test will verify that the core module can communicate with the PC and is able to obtain some results from the test unit.
- The Installation Guide gives instructions about how to set up the system and perform a wider range of *experiments*, so that all the installed modules can be tested using the Dielectric Reference Module (or the ModuLab MTS 0.1 Ω Test Unit for high power applications). A variety of hardware configurations are described, including expanded systems with multiple chasses.
- This User Guide describes how to set up your system to perform *experiments*, using a number of standard connection configurations that will be suitable for most types of material samples. You can set up your *experiments* from the ModuLab XM software, so that the sample is subjected to excitation signals to produce a variety of responses, in terms of waveforms which may be linear, oscillating, staircase, etc. The results can be displayed graphically during the *experiment*, or the stored results can be displayed afterwards and exchanged with other users.

An online Help system is supplied with the ModuLab XM software, so that you can quickly access information about the software features that you are using.

Be careful when lifting and carrying the ModuLab XM system, as it is heavy and has no carrying handles. It should normally be carried by two people, gripping firmly under the footrests at the front and rear.

☞ General Safety Precautions at the beginning of this manual.

2. ModuLab XM MTS Control Features

2.1 INTRODUCTION TO THE USER INTERFACE

The ModuLab XM MTS system is controlled by a PC running the ModuLab XM software which has been installed as described in the ModuLab XM MTS Installation Guide, or the Getting Started Guide.

When the installation is complete, the user will be able to set up *projects*, which define the *experiments* to be performed and the graphical and tabulated display of results.

To start the ModuLab XM MTS software:

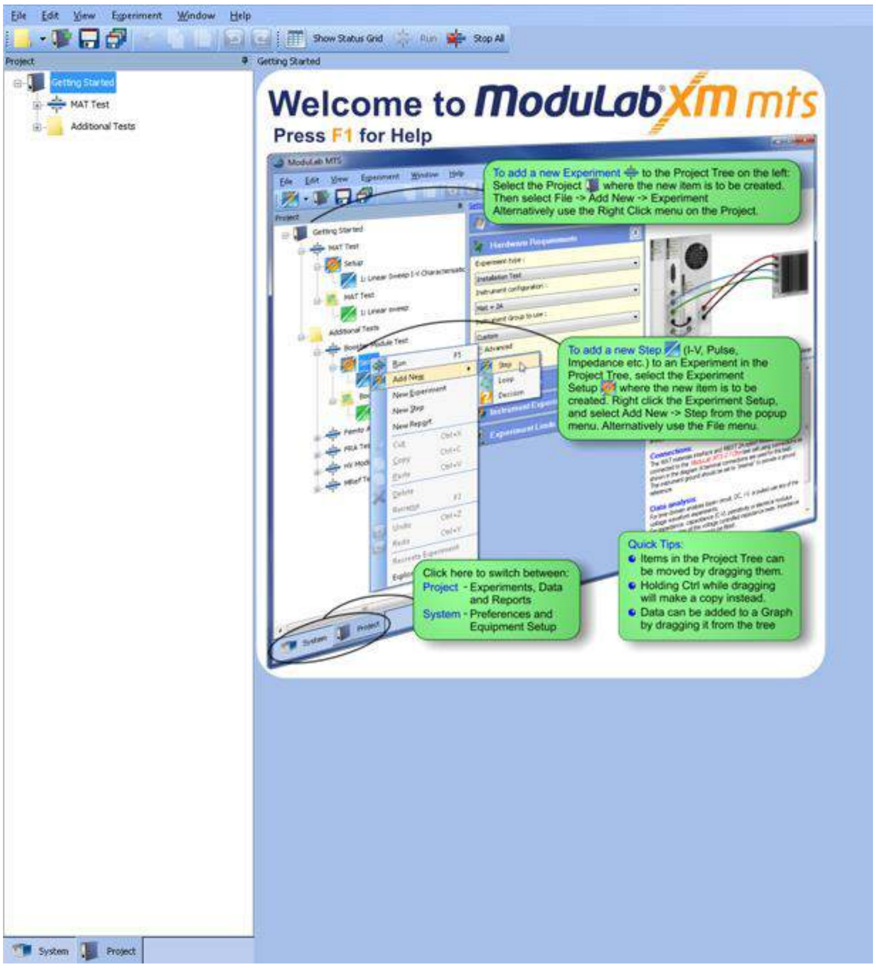
1. On the PC, double-click the ModuLab XM MTS icon on the Windows desktop:

Alternatively, you can navigate to the ModuLab XM MTS application from the Windows Start menu. The path is:

Start → All Programs → Solartron Analytical → ModuLab XM → ModuLab XM MTS

The ModuLab XM MTS software opens, briefly displaying a screen as follows:

This is followed by the opening screen as follows:



This screen has a left-hand navigation panel, displaying the structure of the currently open *project*, in this case Getting Started. The right-hand window displays a screen corresponding to the currently selected item in the navigation panel, in this case a Welcome screen, which is the same for the top level item of all *projects*.

When ModuLab XM MTS is started, it will open a project according to the following rules.

- If the previous session of ModuLab XM was closed while a *project* was open, ModuLab XM will open with the same *project*.
- If the previous session of ModuLab XM was closed without a *project*, ModuLab XM will open without a *project* and the left-hand navigation panel will be empty. You will have to open a *project*, or create a new one.
- If you have just installed ModuLab XM and you are running it for the first time, the Getting Started *project* will open by default.

This User Guide describes how to add a new *project* and create your own *experiments*, but for the purpose of reviewing the user interface, the Getting Started *project* will be suitable.

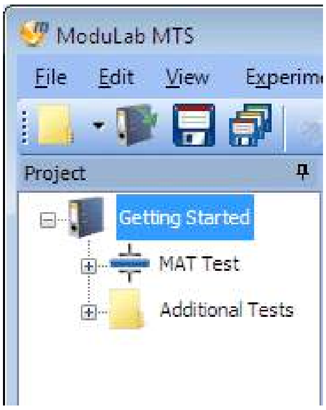
2. If ModuLab XM MTS has opened without a *project*, you will need to open one or create a new one, then continue with these instructions.

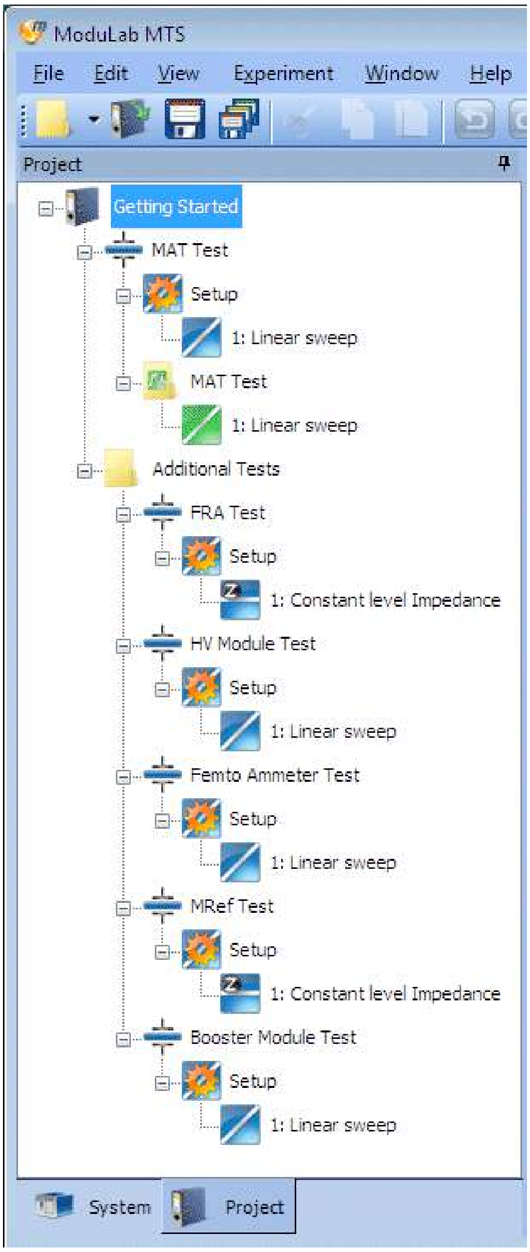
   ☞ Section 5.1.1, Create New Project.

   ☞ Section 5.1.2, Opening and Closing Projects.

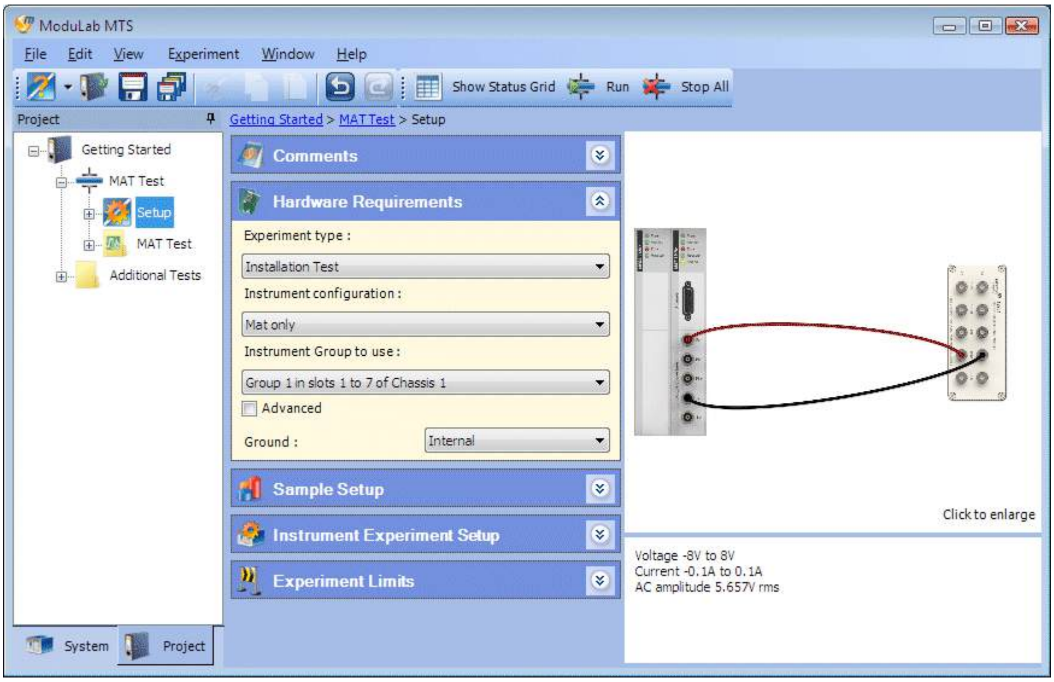
A project normally opens in a semi-collapsed state, showing the first two levels of the item structure in the navigation panel, as shown on the left below.

A *project* structure can be expanded by clicking on any (+) symbols alongside the item names, then clicking the (+) symbols on the subsidiary items. A typical expanded structure for the Getting Started *project*, including a *data* item representing the results of the Materials Core Module Test (MAT Test), is shown on the right below:





3. Click on the items in the *project* structure to display their details in the right-hand window. For example, if you click the Setup item under MAT Test, the *experiment* setup details will appear as follows:

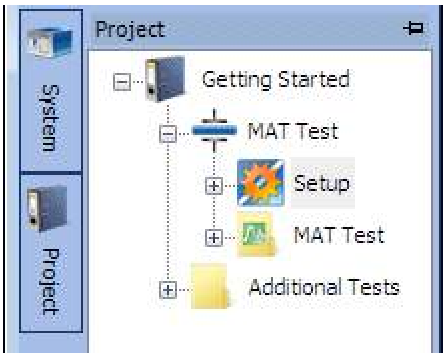


The User Interface can be described generally as follows:

Underneath the title bar there is the menu bar and toolbar, and then there are two windows:

- The left-hand navigation panel contains a tree structure of items that can be expanded and collapsed by clicking their associated (+) and (-) symbols. At the bottom of this window there are two tabs:
  - **System**. This tab displays a tree structure of items that are used to define the user preferences and the equipment, including the chassis and materials core modules, together with their associated optional modules and external units.
  - **Project**. This tab displays a tree structure of *project* items that are used to define *experiments* and *data*.

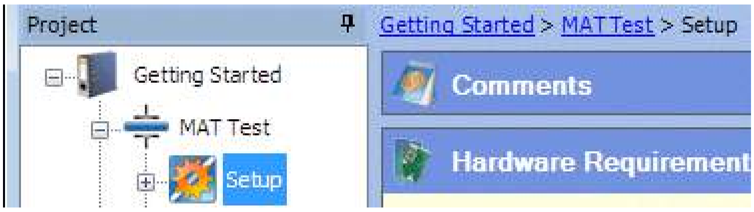
These two tabs can be moved to the top left of the navigation panel, by clicking the pin button at the top right of the panel as follows:



When the tabs are pinned in this way, the navigation panel only appears when the cursor is held over the tab. The tabs can be returned to the bottom of the screen by clicking the pin button again.

- The main right-hand window contains the configuration and data associated with the selected item within the tree structure. This may be divided into sub-screens for different types of display purposes, and some of these can be expanded and collapsed using the arrow buttons:
  .

When an item is selected in the left-hand navigation panel, the path to the item is shown at the top of the right-hand window as follows:



If Show Status Grid is selected from the Experiment menu, a panel appears at the bottom of the right-hand window, showing the status of the modules.

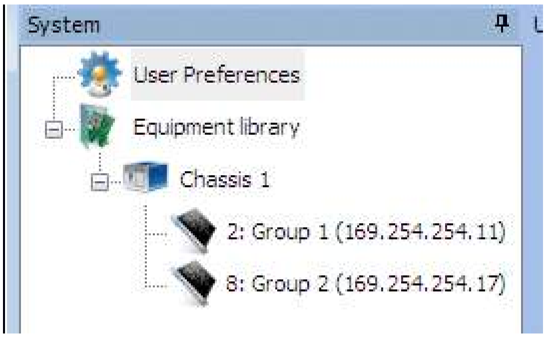
☞ Section 2.6, Status Grid.

At the bottom of the screen there is a small panel which displays status messages, describing the current activity of the system.

☞ Section 2.6.3, Module Information.

2.1.1 System

When the System tab is selected and the tree structure is expanded, the navigation panel is as follows (depending on the installed equipment):



The structure is as follows:

- **User Preferences**. This enables you to give general information about the whole system, including units, messages, graphics and country-specific features.

  ☞ User Preferences, Section 4.1.

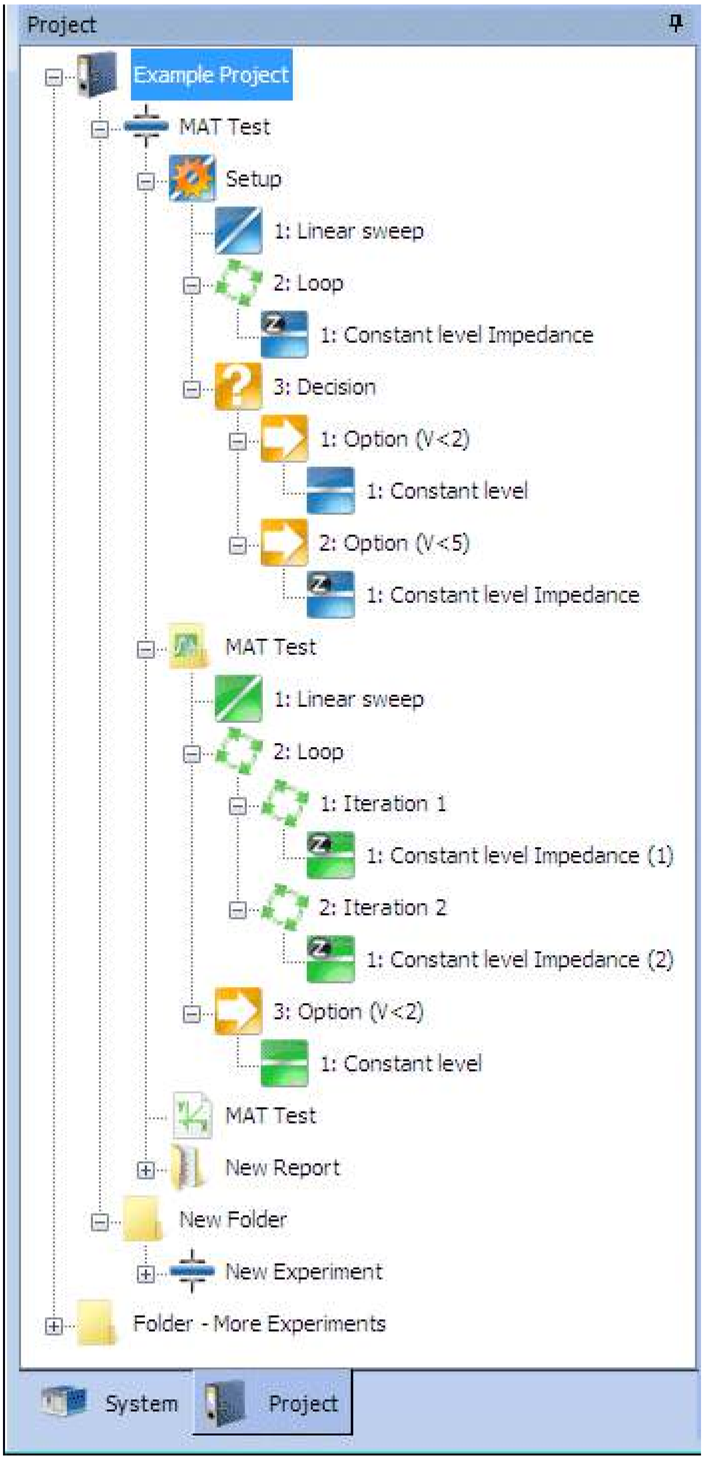
- **Equipment library**. This item displays a summary of the equipment, and there is a structure of sub-items as follows:
  - At the first level there is the chassis, or multiple chasses in an expanded system.
  - At the second level, under the chassis, there are the *instrument groups*, each with a materials core module and optional modules as required. Some of the optional modules are specified in the Instrument Group Setup while others are detected automatically by the system.

    ☞ Instrument Group Setup, Section 4.2.3.

  ☞ Equipment library, Section 4.2.

2.1.2 Project

When the Project tab is selected and the tree structure is expanded, the navigation panel is as follows (using a different *project* in this case instead of Getting Started, with a wider range of features):



The top level item is the *project* name, in this case Example Project. This contains a structure of items, and may include general purpose *folders* in which additional structures may be created.

☞ Folders, Section 2.1.2.1.

A *project* or *folder* can contain the following items:

- **Experiment**. This gives a summary of an *experiment* and the control features that enable you to run it.
    - **Setup**. This describes how the *experiment* is to be performed, including the sample and the modules to be used. An *experiment* may contain *loops* and *steps* as follows:
        - **Loop**. This defines a set of measurements to be taken repeatedly, and may contain any number of *steps* either directly within the *loop* or in additional nested *loops*.
        - **Step**. This defines an excitation signal to be applied to the sample, which may belong to any of the following categories:

          General
          Voltage Waveforms (DC)
          Voltage Controlled Impedance (AC, C-V, Mott-Schottky)

          The *step types* are listed under their appropriate category when a new *step* is added. You can select a *step type* from the list and an appropriate screen will appear, and then you can specify the detailed configuration.

          Steps can exist directly under an *experiment* Setup, or they can be within *loops* to take repeated measurements, or under *decision options*.

          ☞ Step, Section 5.6.
        - **Decision**. This item contains *options* to be evaluated so that steps can be carried out.
            - **Option**. This item, under a *decision*, evaluates a condition and carries out *steps*, depending on the result.
    - **Data**. This is generated by running *experiments* and obtaining results which are displayed as tabulated lists and graphs. If the *experiment* contains *loops* and sub-*loops*, the *data* will be generated at multiple levels in the tree structure. A *data* filename is specified when the *experiment* is run, although it defaults to the *experiment* name.
- **Graph**. This is a graphic display feature that can access the *data* generated by *experiments* and display it with the appropriate axes, and make it accessible to *reports*. This feature can be added to a *project* independently of any *experiments*, and then the *data* from different *experiments* can be imported for display and comparison. Alternatively, it can be created from a *data* item, after running an experiment, and will access all the results of the experiment by default.

  ☞ Graph File, Section 5.11.3.

- **Report**. This is a document containing *experiment* settings and *data*, including connection diagrams, graphic displays, tables and user comments. Reports are generated within a *report folder*, using the Report Writer.

  ☞ Reports, Section 5.13.

Graphs and *report folders* can be added at multiple levels within the *project*, either directly under the *project*, or under an *experiment* or *folder*.

☞ The complete list of items that can be added under other items, using Add New in the File Menu, is in Section 2.4.1.

2.1.2.1 Folders

ModuLab XM MTS uses a system of files and *folders*, based on the Windows directory structure, to build *projects*. The *project* itself is a *folder*, directly under the ModuLab XM folder, so that the pathname for the Example Project might be:

C:\My Data\ModuLab MTS\Example Project

The *project* may contain *experiments*, which are also *folders*. A *folder* representing a *project* or *experiment* has a specific meaning in ModuLab XM, so that it is recognised from its contents and the appropriate item appears in the left-hand navigation panel. Underneath a *project* or *experiment*, you can add sub-folders for general purpose use, with the default name “Folder”, and they can be used as a location for other items including other *experiments*.

You can also add *report folders* to a *project*, *experiment* or general purpose *folder*, and these will be recognised from their contents as having a specific meaning in ModuLab XM. They appear in the navigation panel as *report* items, and when you click on them, a Report Writer appears so that you can generate *report* files from the graph files associated with *experiments*.

☞ Reports, Section 5.13.

Although a *report folder* has the same properties in Windows as any other folder, you cannot add a sub-folder from within ModuLab XM, because it would not make sense to do so. There would be no point, for example, having a sub-*folder* containing an *experiment* , because the *reports* themselves depend on experiments that have already been performed.

☞ Add New in the File Menu, Section 2.4.1, for details of the positions in the *project* structure where *experiments*, *report folders* and general-purpose *folder* items can be added.

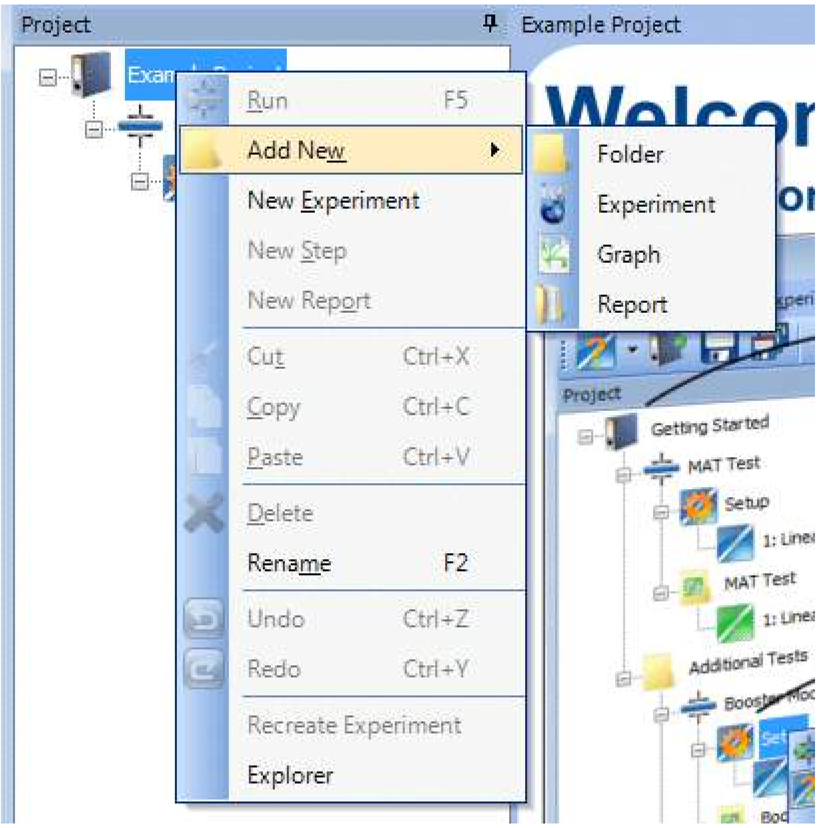
2.2 EDITING THE NAVIGATION PANEL

The tree structure in the navigation panel can be modified in a number of ways.

- New items can be added where appropriate, under the currently selected item, by selecting Add new from the File menu or toolbar, or from the drop down menu that appears when right-clicking the item. The available items depend on the current position in the tree structure.
- Items can be cut, copied, pasted or deleted, using the Edit menu or toolbar, or the drop down menu that appears when right-clicking the item. However, to maintain the structure of the project, these features are only available where appropriate, otherwise they are greyed out.
- Items can be moved from one position in the tree to another, by dragging them up and down, but only in circumstances where the structure of the project can be maintained.
- Items can be renamed so that they represent the features of your *experiment*. To rename an item, click once to select it, then click again, then re-type the name. This feature is not available for the *data* items generated from an *experiment*, but is available for the folders in which they are held.

2.2.1 Navigation Drop Down Menu

When you right-click on an item in the navigation panel, a drop-down menu appears, including sub-menus, containing commands which are mostly from the Menu Bar, and are appropriate for the item. A typical drop-down menu is as follows:



☞ Corresponding Menu Bar commands, Section 2.4.

The following commands are specific to the drop-down menu and do not exist in the Menu Bar:

Rename Experiment

This command is only available when a data folder or sub-item is selected from the navigation panel, and recreates the experiment that was used to generate the data. This is useful if you receive some data from a third party and wish to run the experiment.

Explorer

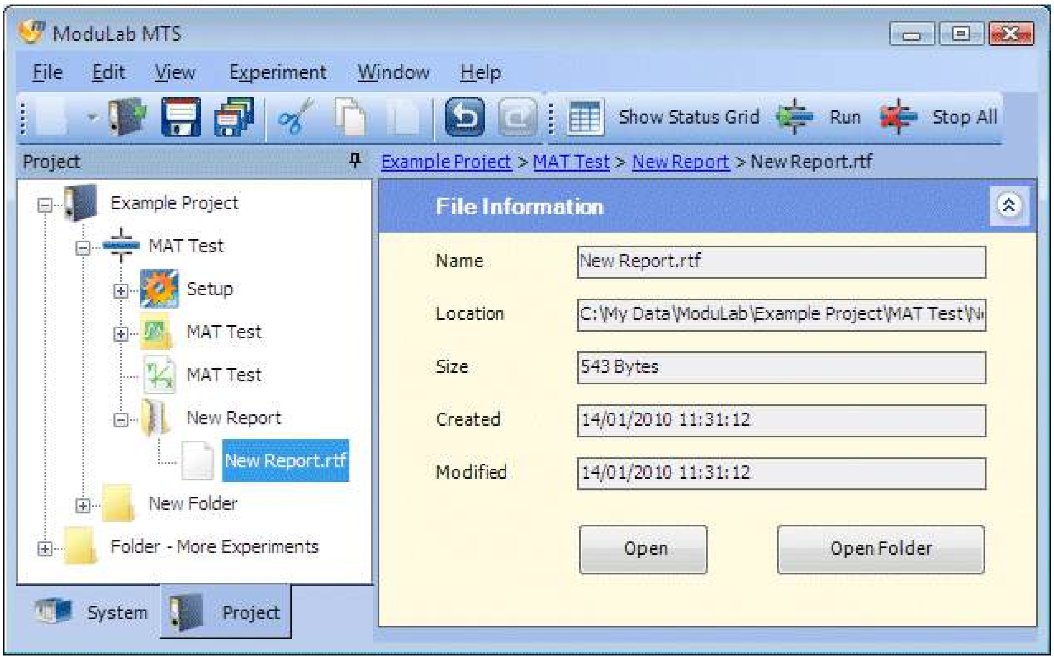
This command opens Windows Explorer at the location in the filing system that represents the currently selected item in the navigation panel. This might be useful, for example, it you want to copy part of the system configuration or data to another part of the filing system, for backup purposes.

2.3 FILENAMES AND EXTENSIONS

The ModuLab XM *project* structure is based on the Windows filing system, with the *project* as a top level *folder*. Within this structure, files with certain extensions are recognised by ModuLab XM and interpreted to create the structure in the navigation panel. For example:

- Files with the INFO extension contain general information about the *project*.
- Files with the DATA extension contain data generated by *experiments*.

If a file exists within the structure, that is not recognised by ModuLab XM, or has been created by ModuLab XM for use with other applications, it will appear in the navigation panel complete with the file extension. This will include CSV files containing exported data, and RTF files representing *reports*. When one of these files is selected in the left-hand navigation panel, a File Information dialogue box will appear as follows:



☞ Section 5.14 for details of this dialogue box, and Section 5.13.2 for an example of how it might be used to open a *report* file in a word-processing application.

2.4 MENU BAR

2.4.1 File Menu

Add New

Add a new item under the currently selected item in the navigation panel. A sub-menu of available additions will appear, otherwise this menu item is greyed out. The available items, according to the current selections, are as follows:

Selected Navigation Panel Tab	Selected Item	Items available for addition
System	Equipment Library	*chassis* virtual *chassis*
	chassis	*instrument group*
	virtual *chassis*	virtual *instrument group*
	instrument group	temperature controller
	virtual *instrument group*	temperature controller
Project	*project*	*folder** *experiment* *graph* *report***
	*folder**	*folder** *experiment* *graph* *report***
	experiment	*folder** *graph* *report***
	Setup (appears automatically under *experiment*)	*step* *loop* *decision*
	loop	*step* *loop* *decision*
	decision	*option*
	option	*step* *loop* *decision*

* A folder that has been added for general purpose use, not representing a *project*, *experiment* or *report*.

** A *report folder*, not the *report* files that it may contain.

☞ New Experiment, New Step and New Report in the Experiment menu, Section 2.4.4. These have the effect of adding items directly under the appropriate top level items (*project*, *experiment* or *experiment* Setup), regardless of the sub-item that has been selected.

☞ Virtual Equipment, Section 4.2.5, for details of virtual *chassis* and virtual *instrument group*.

New Project

Create a new *project*. A dialogue box appears in which you can specify a *project* name and various other features, and then the *project* appears in the navigation panel with the Project tab selected.

If a *project* is already open, containing items that have changed, the Close Project dialogue box will appear, so that you can specify the items that need to be saved, then the new *project* will appear.

☞ Create New Project, Section 5.1.1.

Open Project

Open a *project* that has previously been created. A filing system browser window appears, with an appropriate folder selected (depending on previously opened *projects*), and you can expand the folder and select the *project* to be opened, then click OK. The *project* will appear in the navigation panel with the Project tab selected.

If a *project* is already open, containing items that have changed, the Close Project dialogue box will appear, so that you can specify the items that need to be saved, then the new *project* will appear.

☞ Opening and Closing Projects, Section 5.1.2.

Close Project

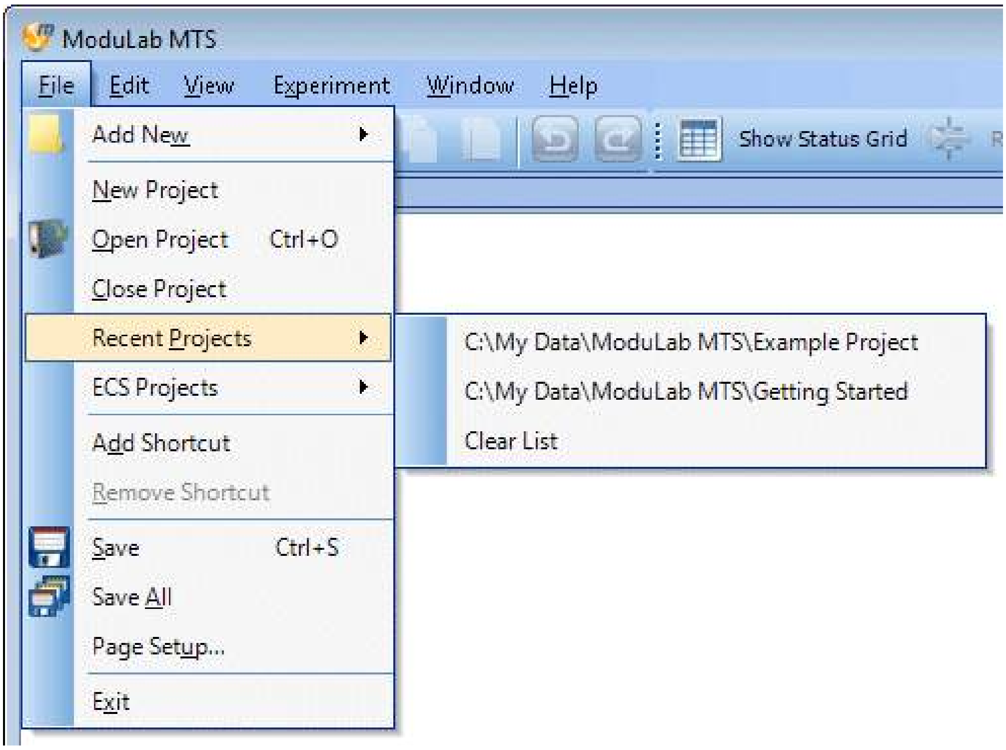
Close the currently open *project*, so that it disappears from the navigation panel. The panel will become empty, including the features that normally appear under the System tab.

If changes to the *project* have been made, the Close Project dialogue box will appear so that you can save the changes, then the *project* will close.

☞ Opening and Closing Projects, Section 5.1.2.

Recent Projects

Display a list of recently opened *projects* as follows:



When a *project* is selected from the list, it will open in the navigation panel and any currently open *project* will be closed.

If changes to the currently open *project* have been made, the Close Project dialogue box will appear so that you can save the changes, then the *project* will close.

☞ Opening and Closing Projects, Section 5.1.2.

If Clear List is selected, all *projects* will be removed from the list so that next time it appears it will display List Empty!

ECS Projects

Open a *project* using the ModuLab XM Electrochemical System. This feature is the same as Recent Projects except that the list of *projects* in the drop down menu will be suitable for ECS. When you select a *project*, the MTS version of the ModuLab XM software will close and the *project* will open in the ECS version, so that ModuLab XM ECS will appear in the title bar as follows:

The ECS Projects item in the File menu will change to MTS Projects so that you can select an appropriate *project* and it will open in ModuLab XM MTS.

Add Shortcut

Add a shortcut folder at the bottom of the tree in the navigation panel, for accessing files anywhere on the filing system. This is initially a blank shortcut which has no destination, and when selected it will display a blank File Information screen. You can then browse the filing system and select a destination folder, and the shortcut will be populated with the files. You can then click on the files and open them from the appropriate applications.

☞ Shortcut Folder, Section 5.14.1.

Remove Shortcut

Remove the selected shortcut folder.

Save

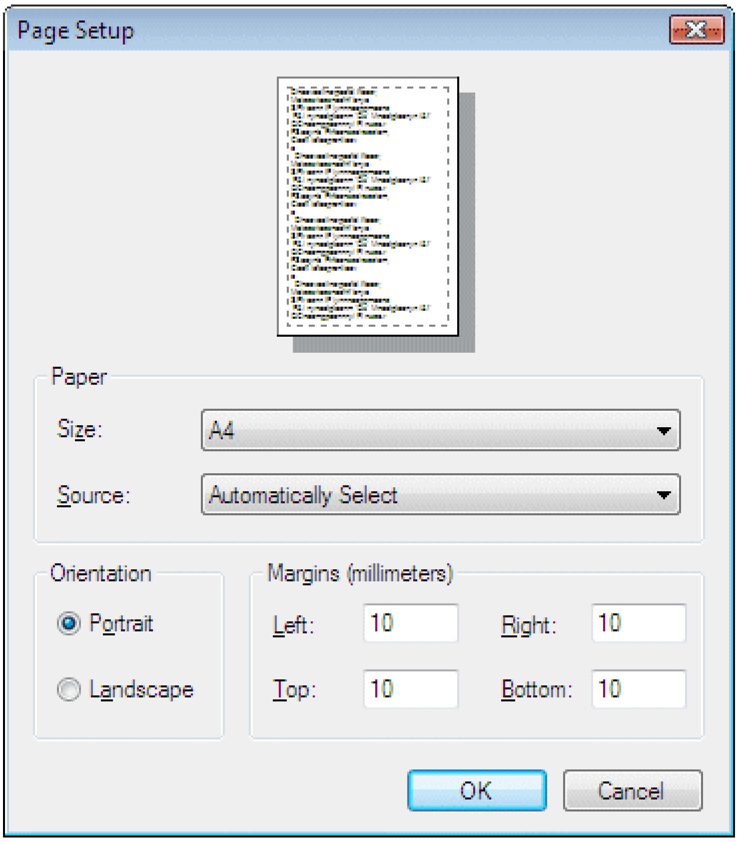
Save the *project* so that it becomes updated with the currently selected *experiment*.

Save All

Save the whole *project* including all the *experiments*.

Page Setup

Set up the page size and orientation, etc., for printing. A standard Windows dialogue box appears as follows:



Exit

Close the ModuLab XM MTS software.

If changes to the currently open *project* have been made, the Close Project dialogue box will appear so that you can save the changes, then the ModuLab XM software will close.

☞ Opening and Closing Projects, Section 5.1.2.

2.4.2 Edit Menu

Undo

Undo the latest change to the *project*. Click repeatedly to work backwards and undo the latest history of changes. If no changes have been made since the *project* was opened, this menu item is greyed out.

In some circumstances the Undo command may be appended by the latest action. For example, if you have just added an item to the navigation panel, it will say Undo Insert Node.

Redo

Redo the latest change after selecting Undo. If Undo has not been used, this menu item is greyed out.

Cut

Delete the currently selected item, including the structure of sub-items, from the navigation tree and store it in the clipboard.

Copy

Copy the currently selected item, including the structure of sub-items, to the clipboard without deleting it from its current location.

Paste

Paste an item, including a structure of sub-items, that has been previously copied to the clipboard using Cut or Copy. The item will be pasted under the currently selected item, but only if the operation maintains a valid structure of items and sub-items (for example you can't paste an *experiment* under another *experiment*).

The item can be pasted to another *project*, but you can't have two *projects* open at once. You have to cut or copy the item from the current *project*, then close the *project* and open a new one, then paste the item.

Delete

Delete the currently selected item without copying it to the clipboard. The structure of sub-items will also be deleted.

Rename

Rename the currently selected item. A text cursor will appear on the item.

You can also rename an item by selecting it, pausing for an interval that is too long for a double-click, then selecting it again.

2.4.3 View Menu

Project

Select the *project*, in the navigation panel.

Equipment

Select the Equipment library, in the navigation panel.

Options

Select the User Preferences, in the navigation panel.

Tree Size Small
Tree Size Medium
Tree Size Large
Tree Size Huge

Specify the size of the icons in the navigation panel.

2.4.4 Experiment Menu

Show Status Grid

Display the current status of the modules. A display panel appears which is updated with measurements when an *experiment* is running and provides access to Start/Stop and Pause/Continue, etc. This is a toggle feature so that it shows or hides the status grid.

☞ Status Grid, Section 2.6.

Stop All

Stop all *experiments* from running.

Run

Display the Start Experiment screen associated with an *experiment* structure, when an item within the structure is selected. If the Start Experiment screen is already on display, the experiment will run, same as pressing the Run button within the screen.

New Experiment

Add a new *experiment* to the *project*, together with Setup and *step* items. The *experiment* will be added directly under the *project*, regardless of the item that has been selected in the *project* structure.

☞ Add New from the File menu, Section 2.4.1, to add an *experiment* as a sub-item within a *folder*.

New Step

Add a new *step* to an *experiment*. The *step* will be added directly under the *experiment* Setup, regardless of the item that has been selected in the *experiment* structure.

☞ Add New from the File menu, Section 2.4.1, to add a *step* as a sub-item within a *loop*.

New Report

Add a new *report folder* to an *experiment*, The *report folder* will be added directly under the *experiment*, regardless of the item that has been selected in the *experiment* structure.

☞ Add New from the File menu, Section 2.4.1, to add a *report folder* as a sub-item within a general-purpose *folder*, or directly under the *project*.

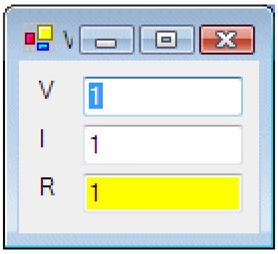
2.4.5 Window Menu

Reset Toolbar

Reset the toolbar to its default configuration after changes have been applied. (The toolbar can be customised from the drop-down menu at the right).

V=IR calc

This is a simple calculator that works out values of the equation V=IR. There are two data entry fields with white backgrounds and a result field with a yellow background as follows:



Type a number in any data entry field and the value in the result field will be re-calculated. If you click the result field, it will turn white and another field will become the result field, according to the following sequence:

Click V, when yellow, to make R the new result field.
Click I, when yellow, to make V the new result field.
Click R, when yellow, to make I the new result field.

2.4.6 Help Menu

Contents

Display the ModuLab XM MTS help system in a window with a navigation panel on the left and the help topics on the right. The navigation panel has four tabs:

Contents	Navigate a table of contents to display the help topics. This tab is selected by default when Contents is selected from the Help menu.
Index	Make a selection from an alphabetical list of index entries and display the associated topics.
Search	Search the Help system for any word or phrase and display the associated topics.
Favorites	Add the currently displayed topic to your list of favorites, for further reference.

Index

Display the ModuLab XM MTS help system in a window with a navigation panel on the left and the help topics on the right. The tabs are as described above, under Contents, but the Index tab is selected.

FAQ

Display a list of frequently asked questions, as a topic within the help system.

PDF Manuals

Display a set of folders containing the ModuLab XM ECS and MTS manuals in Adobe Acrobat PDF format. These files have been compiled as tagged PDF so that the cross-references and table of contents are hyperlinked to their destinations, and the section headings can be displayed in a side panel for easy navigation. The files can be displayed using the Adobe Reader, available as a free download from:

www.adobe.com

Check for updates

Display the Downloads page from the Solartron website. Downloads are available for a number of Solartron products.

Technical support

Display the Technical Support page from the Solartron website.

About

Display the ModuLab XM MTS splash screen giving the current version number. Click the screen to close it.

2.5 TOOLBAR

The toolbar emulates some of the commonly used commands available from the menu bar, as follows:

Add New

Add a new item under the currently selected item in the navigation panel. The drop-down menu at the right of the button gives a list of available additions. If there are no additions, the button and menu are greyed out.

☞ This button is equivalent to Add New in the File Menu, Section 2.4.1.

The icon used for this button depends on what can be added. When you click the icon, the corresponding item is added, otherwise you can click the drop-down menu to add alternative items. The icons are as follows:

The folder icon appears in circumstances where a folder can be added.

The step selection icon appears when a *step* can be added to an *experiment* setup, *loop* or *decision option*.

The option icon appears when an *option* can be added to a *decision*.

The chassis icon appears when a *chassis* can be added to the equipment library.

The instrument group icon appears when an *instrument group* can be added to a *chassis*.

Open Project

Opens a *project* that has previously been created. A filing system dialogue box appears with an appropriate folder selected (depending on previously opened *projects*) and you can expand the folder and select the *project* to be opened, then click OK.

☞ This button is equivalent to Open Project in the File Menu, Section 2.4.1.

Save

Save the *project* so that it becomes updated with the currently selected *experiment*.

☞ This button is equivalent to Save in the File Menu, Section 2.4.1.

Save All

Save the whole *project* including all the *experiments*.

☞ This button is equivalent to Save All in the File Menu, Section 2.4.1.

Cut

Delete the currently selected item from the navigation tree and store it in the clipboard.

☞ This button is equivalent to Cut in the Edit Menu, Section 2.4.2.

Copy

Copy the currently selected item to the clipboard without deleting it from its current location.

☞ This button is equivalent to Copy in the Edit Menu, Section 2.4.2.

Paste

Paste an item that has been previously been copied to the clipboard using Cut or Copy. The item will be pasted under the currently selected item, which may be in a different *project*.

☞ This button is equivalent to Paste in the Edit Menu, Section 2.4.2.

Undo

Undo the latest change to the *project*. Click repeatedly to work backwards and undo the latest history of changes. If no changes have been made since the *project* was opened, this menu item is greyed out.

☞ This button is equivalent to Undo in the Edit Menu, Section 2.4.2.

Redo

Redo the latest change after selecting Undo. If Undo has not been used, this button is greyed out.

☞ This button is equivalent to Redo in the Edit Menu, Section 2.4.2.

Show Status Grid

Display the current status of the modules. A display panel appears which is updated with measurements when an *experiment* is running and provides access to Start/Stop and Pause/Continue, etc. This is a toggle button so that it shows or hides the status grid.

☞ Status Grid, Section 2.6.

☞ This button is equivalent to Show Status Grid in the Experiment Menu, Section 2.4.4.

Run

Display the Start Experiment screen associated with an *experiment* structure, when an item within the structure is selected. If the Start Experiment screen is already on display, the experiment will run, same as pressing the Run button within the screen

☞ This button is equivalent to Run in the Experiment menu, Section 2.4.4.

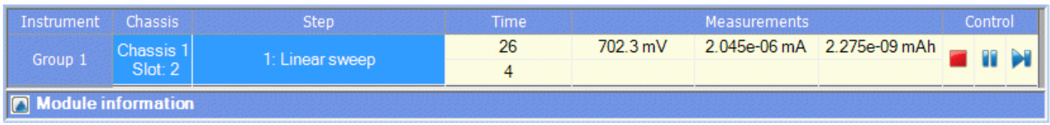
Stop All

Stop all *experiments* from running.

☞ This button is equivalent to Stop All in the Experiment menu, Section 2.4.4.

2.6 STATUS GRID

If Show Status Grid is selected from the Experiment menu, a panel appears at the bottom of the right-hand window, showing the status of the modules as follows:



There is one row of status information for each *instrument group* that has been installed in the system, and has been tested using the Test button in the Instrument Group Setup.

☞ Instrument Group Setup, Section 4.2.3.

This example shows the status of a single group while an experiment is running. If you double-click on a row in the status grid, while an experiment is running, the appropriate graph will appear, and will display each new point as the measurements are taken.

The columns in the tabulated list are:

Instrument

The *instrument group* which is used to take measurements.

Chassis

The chassis and slot to which the materials core module is fitted.

Step

The name of the *step* that is currently being run, if an *experiment* is running on this module, otherwise the status is Idle. If an *experiment* pauses or stops because it has reached an *experiment* limit or produced an error, this column will give status details.

☞ Paused Experiments, Section 2.6.1.

Time

The top row displays the elapsed time for the *step*, and the bottom row displays the time remaining.

Measurements

The top row displays the DC measurements for the *step*, including voltage, current and charge. The bottom row displays the AC measurements, if applicable, including frequency, impedance magnitude and phase.

The measurements appear with background colours that change according to the following circumstances:

- A yellow background means the measurement is within the voltage or current range specified in the Instrument Experiment Setup, or if the range is set to Auto, the measurement is within the range selected by the system.

  ☞ Instrument Experiment Setup, Section 5.3.4.

- A blue background means the measurement is “under-range”. It is below the voltage or current range specified in the Instrument Experiment Setup, or if the range is set to Auto, it is below the range selected by the system.
- An orange background means the measurement is “over-range”. It is above the voltage or current range specified in the Instrument Experiment Setup, or if the range is set to Auto, it is above the range selected by the system.

  NOTE: In all the above circumstances, if auto-ranging is used, the measurements are likely to be temporarily under-range or over-range while the system is searching for the correct range to use. For impedance steps, the DC current may always be under-range because the AC current is normally larger than the DC current and the under-range detection is based on the DC measurements.

- A red background indicates that an *experiment* limit has been reached. When this happens, the *experiment* will pause, but can be made to continue under appropriate circumstances using the control buttons at the right of the status grid. *Experiment* limits can be imposed from both the ModuLab XM hardware and software.

  ☞ Experiment Limits, Section 5.3.5.

  ☞ Paused Experiments, Section 2.6.1.

Control

The following control buttons are available:

Stop the *experiment*. This button appears only when an experiment is running (including open circuit measurements).

☞ Open Circuit Measurements, Section 2.6.1.

Pause the *experiment*. This button appears only when an experiment is running (excluding open circuit measurements).

Resume an *experiment* that has been paused, so that it continues taking measurements from the point within the *step* where it was paused. This button only appears when the *experiment* has been paused, either by the user by pressing the Pause button, or by the system because a problem has occurred with the *experiment*.

Skip the current *step* and move on to the next *step*. This button appears only when an *experiment* is running (excluding open circuit measurements).

Start measuring the open circuit voltage. This button only appears when the *experiment* has been stopped after taking some measurements, otherwise the system will not know which configuration of modules to use.

2.6.1 Paused Experiments

An *experiment* will pause if the Pause button in the Status Grid is pressed by the user, or if something happens during the *experiment* that causes a measured value to reach a specified limit.

Experiment limits can be imposed in two ways:

- From the ModuLab XM software, by specifying limiting values of voltage, current and charge in the Experiment Limits sub-screen.

  ☞ Experiment Limits, Section 5.3.5.

- From the ModuLab XM hardware. The Materials Core Module is fitted with short circuit protection so that a switch opens when the current reaches an unsafe level. If this happens, the Error (red) LED on the module front panel will come on, but it is unlikely to happen because of various built-in safeguards.

  ☞ Installation Guide.

An *experiment* is much more likely to pause because of the Experiment Limits in the software, and it might happen in the following circumstances:

- An *experiment* limit specified in the software has been exceeded. This can be resolved by changing the limits, or setting up the *steps* so that the measurements remain within the required limits.

- Something has gone wrong with the sample or the connecting cables, so that a short circuit has caused a measurement to reach an *experiment* limit.

If a limit is reached, for whatever reason, the appropriate values in the status grid will be highlighted with a red background and the reason for pausing the *experiment* will be given in the Step column.

Here is an example of a status grid where the *experiment* has paused during a linear sweep because the measured current has reached a limiting value of 5µA:

Instrument	Chassis	Step	Time	Measurements			Control		
Group 1	Chassis 1 Slot: 2	1: Linear sweep	25	497.4 mV	**0.005001 mA**	1.726e-05 mAh			
		Experiment limit exceeded	24						

If the Stop button in the Status Grid is pressed, while the *experiment* is paused, the *experiment* will stop and the status grid will be as follows:

Alternatively, if the Skip button in the Status Grid is pressed, while the *experiment* is paused, it will continue with the next *step*, if there is one, and will complete successfully if the *experiment* limit is not reached.

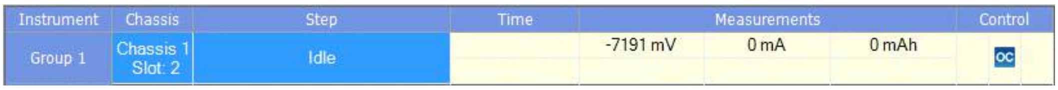
2.6.2 Open Circuit Measurements

In some circumstances, an open circuit measurement might have to be taken at the beginning of an *experiment*, for example a solar panel might have become charged, or a capacitor may have retained some charge from a previous *experiment* or other electrical process.

When an *experiment* is set up and ready to run, and the OC Measure button is pressed in the Start Experiment screen, the Status Grid appears as follows:

☞ Start Experiment, Section 5.2.2.

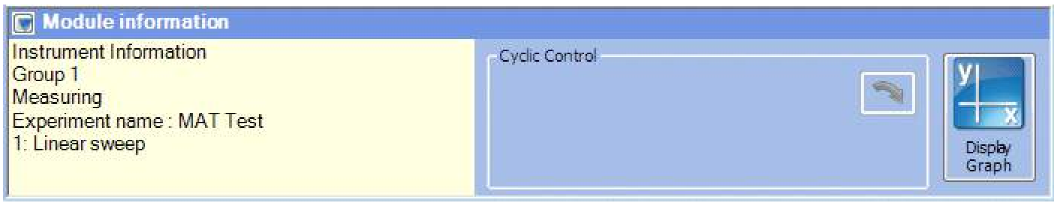
The Step column displays Measuring OCV and the results in the Measurements column will be updated as the measurements are taken. When the red control button is clicked, the measurements will stop and the status will change to Idle, as follows:



The red control button has disappeared and has been replaced by an OC button, for re-starting the Open Circuit measurements. This is the same as the OC Measure button in the Start Experiment screen.

2.6.3 Module Information

If you click the Module Information button at the bottom of the Status Grid, a sub-panel opens to give information about the currently selected *instrument group* as follows:



This panel gives the status of the selected *instrument group*, under the heading Instrument Information, as follows:

- The *instrument group*, for example Group 1.

- The current activity being performed by the group, for example Measuring. This corresponds to the Status field in the Equipment Summary and Start Experiment screens.

  ☞ Equipment Summary, Section 4.2.1.

  ☞ Start Experiment, Section 5.2.2.

- The *experiment* name, for example MAT Test.
- The *step* that is currently running, same as the Step column in the status grid.

The following additional features are available:

Cyclic Control

This button reverses the direction of cyclic *steps*, for the selected *instrument group*.

Display Graph

This button displays a graph of the data being generated by the currently selected *instrument group*.

2.7 ERROR AND WARNING ICONS

In some of the screens in the ModuLab XM system, error and warning icons will appear if an inappropriate entry is made in a field. The icons will flash for a few seconds when they first appear, then they will become steady.

There are two types of warning:

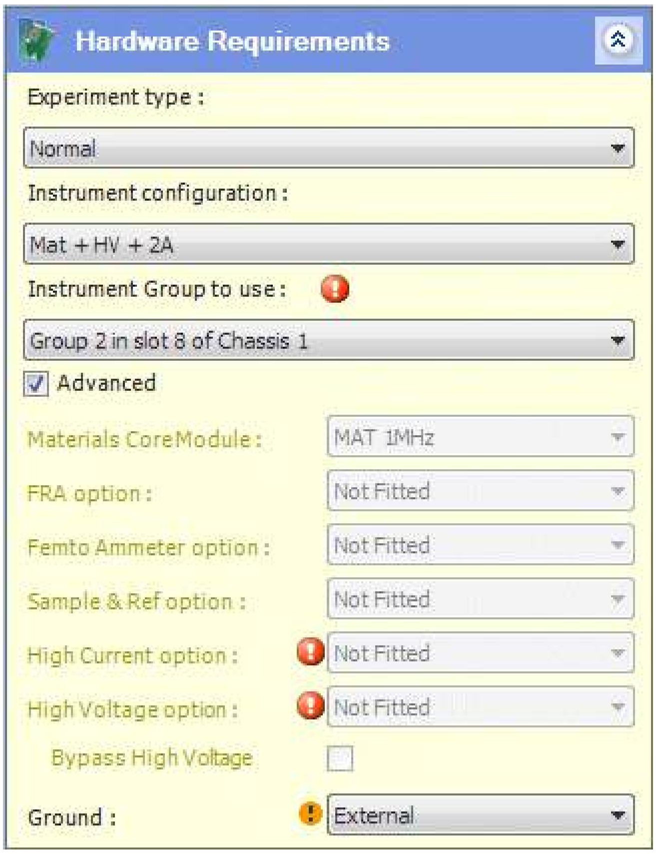
A red error icon appears if a selection is made that will cause the system to function incorrectly. An *experiment* will not run if there is an error.

For example, in the Hardware Requirements sub-screen, if you select an Experiment type and Instrument configuration that requires some optional modules, and then you select an Instrument Group to use that does not have the modules fitted, a red error icon will appear alongside the module fields.

An amber warning icon will appear if a selection is made that allows the system to function, but possibly not at its optimum performance. A warning will not prevent an *experiment* from running.

For example, if you select an entry for grounding that might be inappropriate, an amber warning icon will appear.

A screen showing red and amber icons is as follows:



☞ Hardware Requirements, Section 5.3.2.

2.8 CLOSING MODULAB XM

The ModuLab XM application can be closed using either of the following methods:

- Using Exit, from the File menu.
- Using the control button at the top right corner of the main application window.

In either case, the *project* will be closed and the Close Project dialogue box will appear asking you to save changes to the *project*.

☞ Opening and Closing Projects, Section 5.1.2.

3. Setting Up and Running Experiments

3.1 OVERVIEW

This chapter describes how to set up and run *experiments* with the ModuLab XM MTS system connected to a number of different types of sample according to a set of pre-defined hardware and connection configurations that are specified in the ModuLab XM MTS software.

Before you can perform any of these *experiments*, it will be necessary to install the system and complete the installation tests, as described in the Getting Started Guide and Installation Guide, and the *experiments* that you are able to perform will depend on the modules that are installed.

A number of ready-made *experiments* are available with the ModuLab XM software, for use with the ModuLab Test Unit (or the ModuLab 0.1 Ω Unit for high power applications), and these are described in the Installation Guide. However, because of the wide variety of material samples, it is impractical to provide examples for use with real *experiments*. Instead we will see how to create your own *experiment*, starting with a new *project*.

3.2 AN EXAMPLE EXPERIMENT

In this example, an *experiment* is performed on a real material sample, not a test unit. The sample is subjected to a DC Linear Sweep, using a materials core module without any optional modules (although you can specify additional modules and use the appropriate configuration as required). The results are displayed as graphs and tables. The *experiment* is then repeated, using a core module and a frequency response analyzer, with the same DC Linear Sweep followed by a Constant Level Impedance *step*, and the results are again displayed as graphs and tables.

In the following sub-sections we will see how to do the following:

☞ Create a New Project including an Experiment (Section 3.2.1)

☞ Set up the Experiment (Section 3.2.2)

☞ Set up the Step (Section 3.2.3)

☞ Connect the Hardware and Run the Experiment (Section 3.2.4)

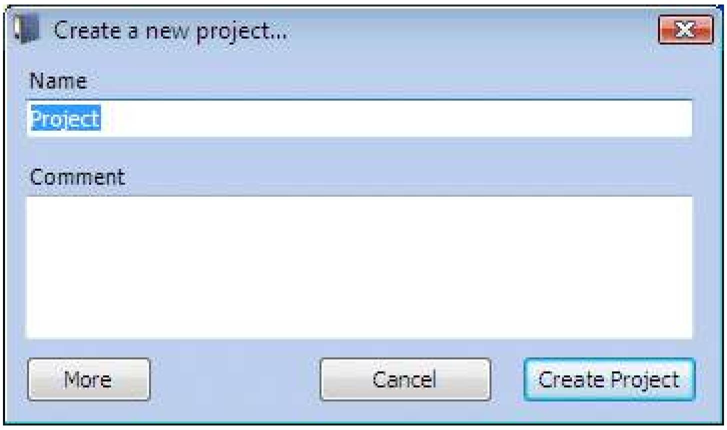
☞ Display Graphs and Tables (Section 3.2.5)

☞ Add an AC Step and repeat the Experiment (Section 3.2.6)

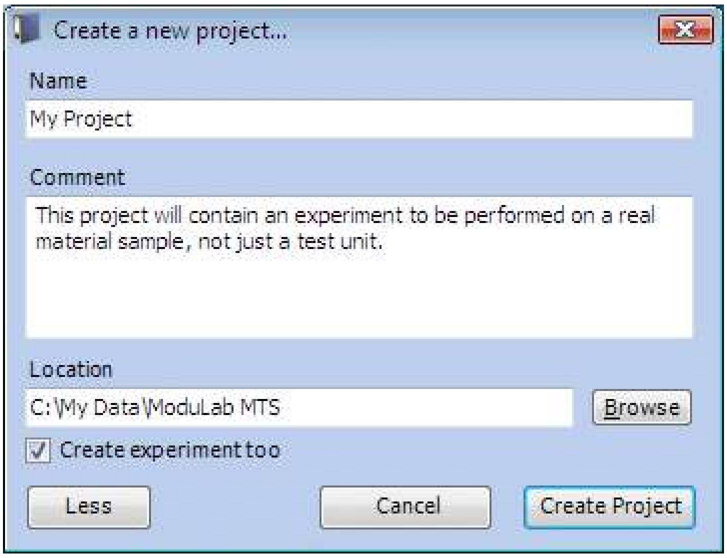
3.2.1 Create a New Project including an Experiment

When a new *project* is created, it contains a single *experiment* and *step* by default, although you can add new items as appropriate. To create a new *project* with an *experiment* and *step*, proceed as follows:

1. Run the ModuLab XM MTS software and select New Project from the File menu. A dialogue box will appear as follows:

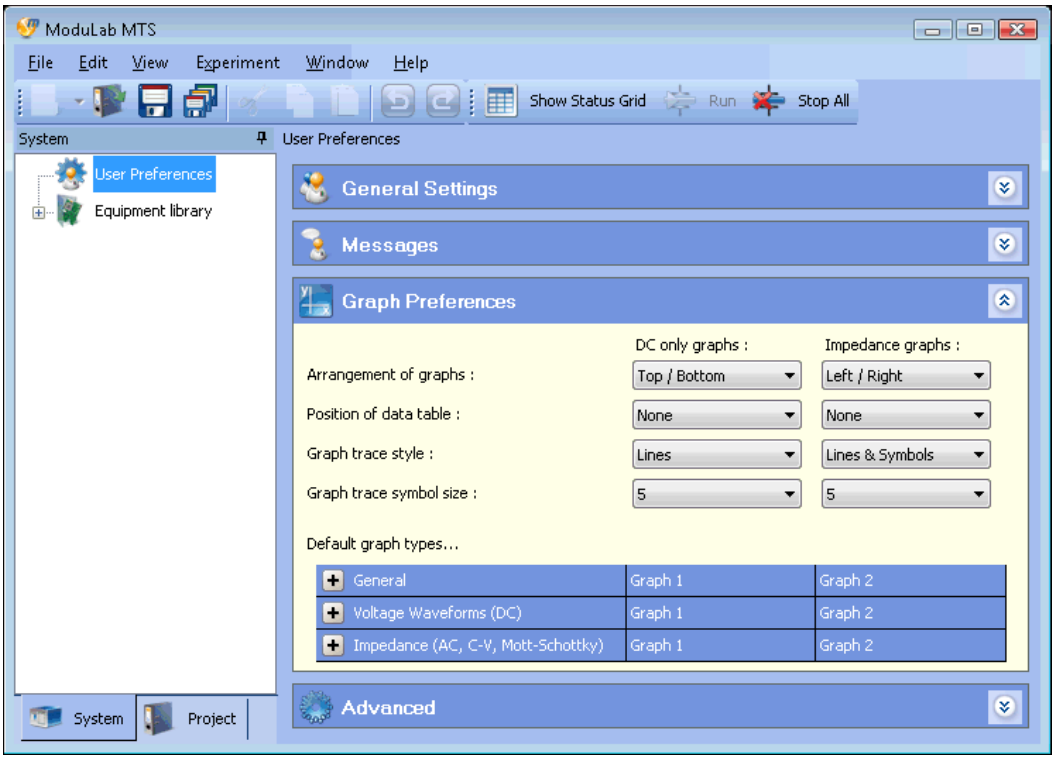


2. In the Name field, type a *project* name, for example My Project.
3. If required, type a description of your *project* in the Comment field, for example some details of the *experiments* to be performed.
4. Click the More button to display the expanded dialogue box as follows:

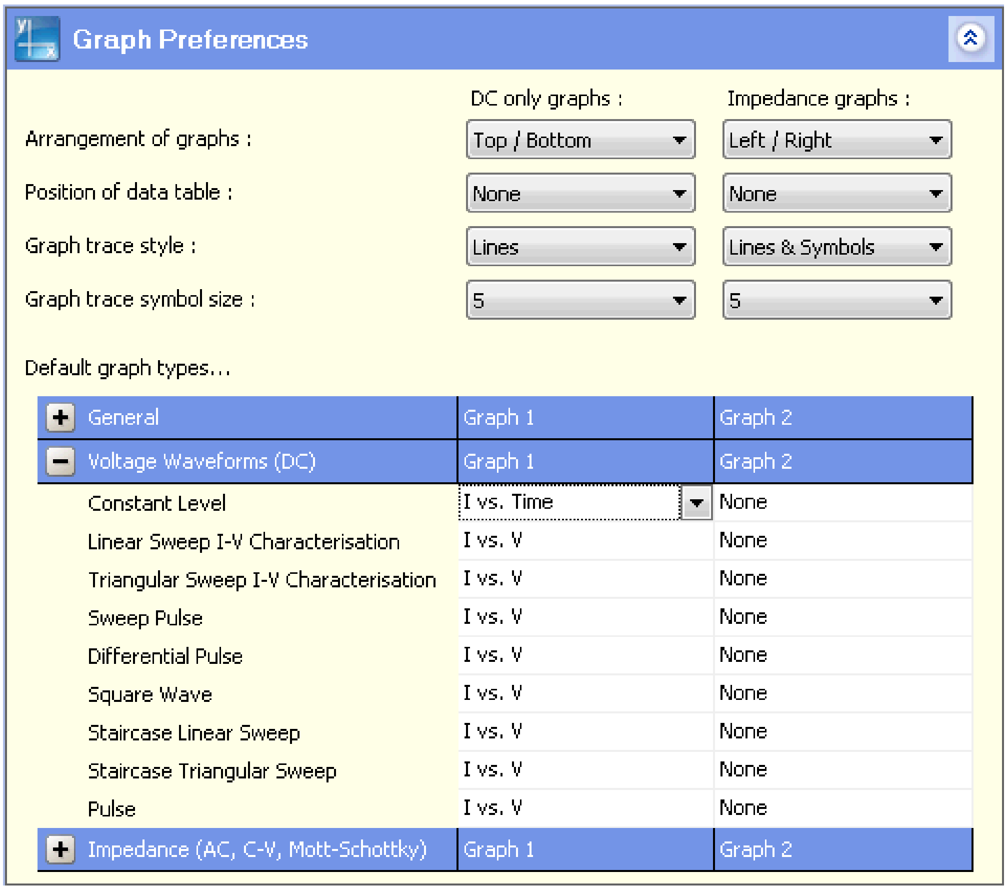


5. Make sure the Create experiment too box is checked, then click Create Project. A structure of items will appear in the navigation panel, depending on the tab that has been selected at the bottom of the panel:
   - If the System tab is selected, the User Preferences and Equipment library will appear, although they do not belong to the *project*. The User Preferences are specific to the user of Windows, and the Equipment library is defined during the system installation.
   - If the Project tab is selected, the *project* name and structure of items appears.

6. Click on the System tab, then click on User Preferences to display the Preferences as follows:

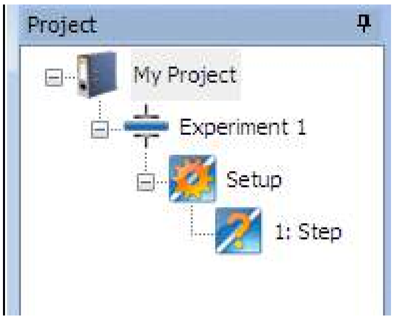


7. In the Graph Preferences sub-screen, click on the row for Voltage Waveforms (DC), to expand it and display the default graph types as follows:



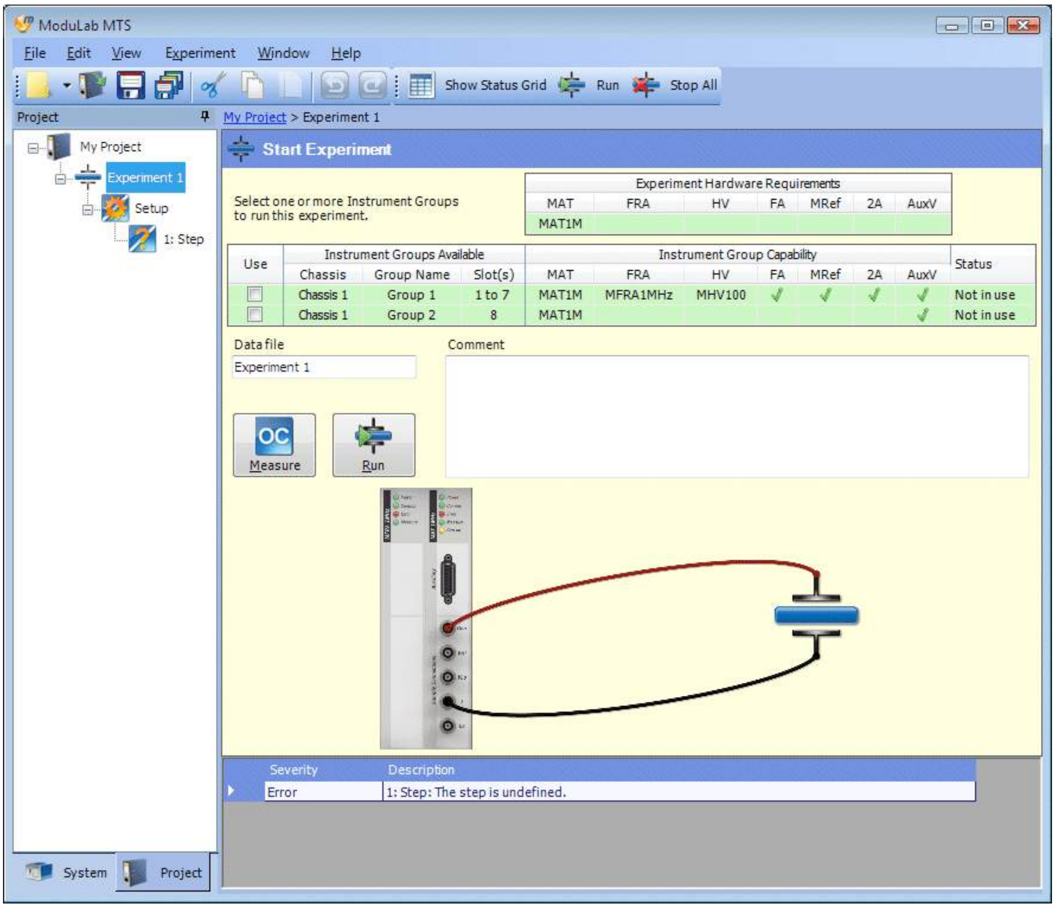
8. Check that the default graph types for Linear Sweep I-V Characterisation are I vs. V for Graph 1 and None for Graph 2. If required, click on the appropriate cells to display the list boxes of graph types, and specify the correct options.

9. Click on the Project tab, at the bottom of the navigation panel, to display the *project* name as follows:



10. Make sure the *project* structure is fully expanded. If collapsed, click on the (+) symbol on the *project* name, and on the sub-items, to expand the *project* structure.

11. Click on the *experiment* to display the Start Experiment screen as follows:



This screen has the following features:

- There is a tabulated list of Experiment Hardware Requirements, which specifies by default that a materials core module is required.
- There is a tabulated list of Instrument Groups Available, together with their hardware specifications under Instrument Group Capability. The available hardware, including all the optional modules, was detected by the ModuLab XM software, or defined by the user, during the system installation. Each *instrument group* occupies one row in the table, and the check boxes in the Use column specify which groups are to be used for the *experiment*. Multiple boxes can be checked to run the *experiment* on multiple samples, but only one will be used in this example. An *instrument group* can only be used for an *experiment* if it meets or exceeds the Experiment Hardware Requirements, otherwise the row in the tabulated list will turn red.

  ☞ For example, the row representing Group 2 turns red when the experiment includes an impedance *step*, because it does not have an FRA, as shown in Section 3.2.6, step 7.

- There is a connection diagram showing how the core module and optional modules should be connected to the sample. This diagram could be any one of a number of standard configurations available from the Hardware Requirements in the *experiment* setup screen.

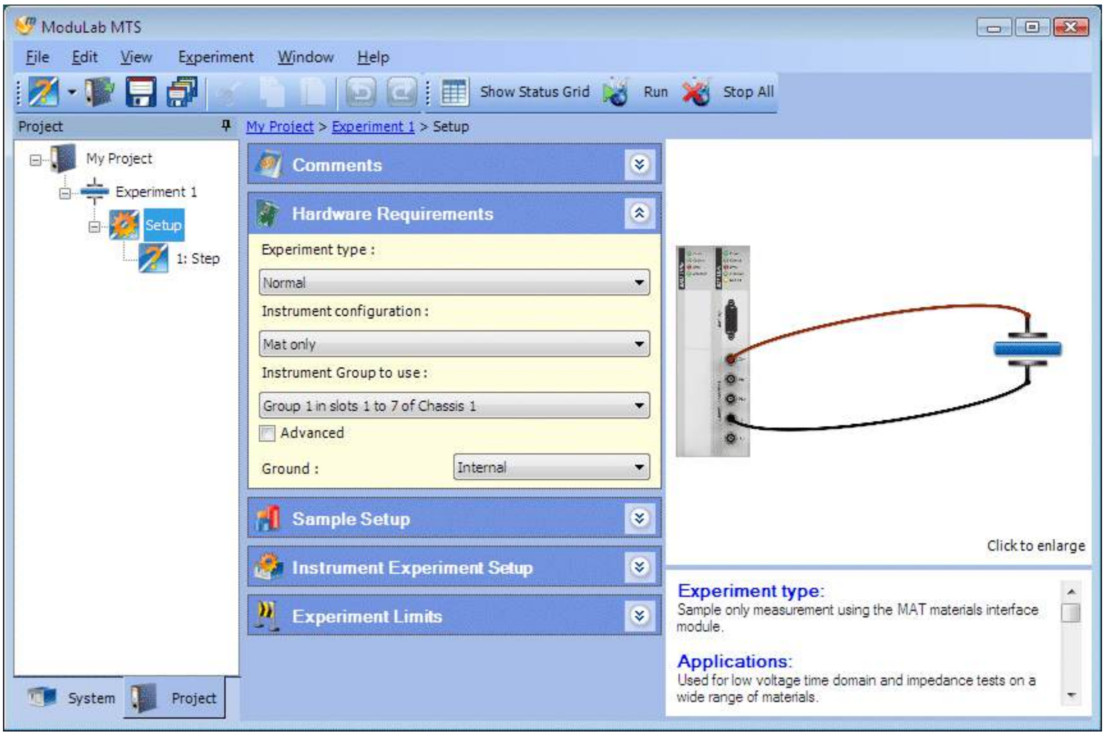
  ☞ Set up the Experiment, Section 3.2.2.

- There is an OC Measure button which displays open circuit measurements on the sample, in case you want to see how the sample is performing without an excitation signal, before you run the *experiment*.
- There is a Run button which runs the *experiment* and collects data, and stores it in the data file that is named in the field above the button. The Run button should only be used when the *experiment* has been fully defined and is expected to obtain some meaningful results.

3.2.2 Set up the Experiment

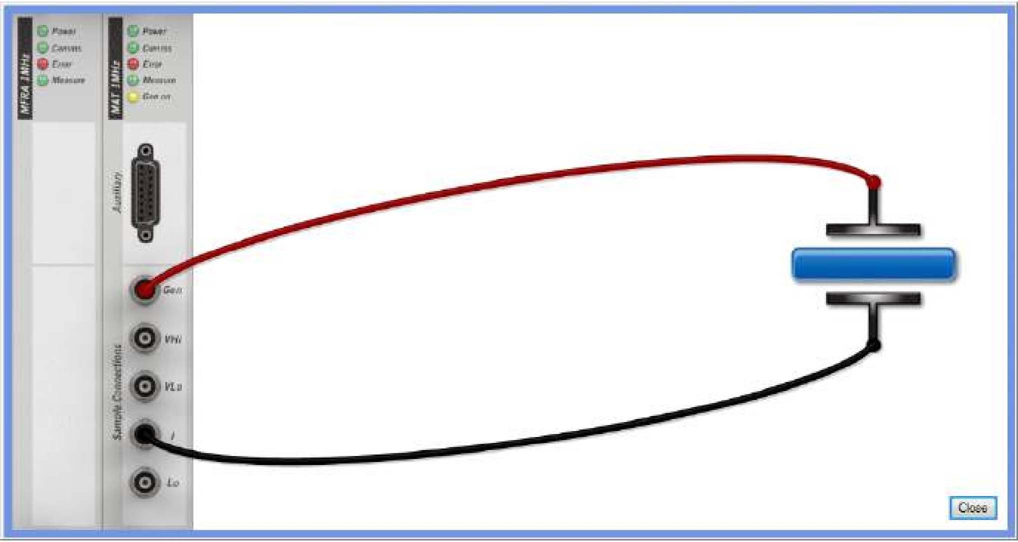
When you have added the new *project* and *experiment*, as described in the previous section, you can set up the *experiment* as follows:

1. Click on Setup, in the navigation panel, to display the *experiment* setup as follows:

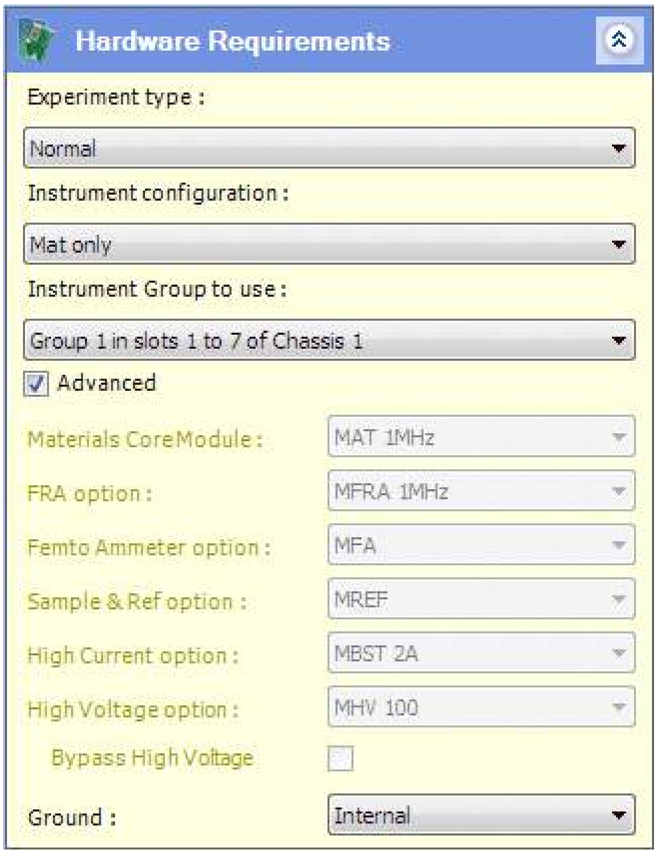


This screen has a connection diagram in the top right corner and a description underneath. The central column contains a number of sub-screens which you can use to configure the *experiment*.

2. If required, you can click on the connection diagram to display an enlarged view as follows, then click the Close button to return to the *experiment* setup screen.



3. Make sure the Hardware Requirements sub-screen is expanded, using the arrow button if necessary, and click the Advanced check box so that the sub-screen appears as follows:



This screen contains a set of list boxes so you can configure the *experiment* to use the appropriate hardware.

☞ Hardware Requirements, Section 5.3.2.

NOTE: If there is only one *instrument group*, the Instrument configuration list box will not display the slot numbers and chassis number, so the field will be reduced to:

Group 1

4. Select the appropriate entries from the Experiment type and Instrument configuration list boxes, and the corresponding connection diagram and description will appear.

5. The Instrument Group to use field defaults to the first group that meets the requirements of the experiment, in the tabulated list in the Start Experiment screen. Select the appropriate group, if this is not the one you want to use.

   ☞ Start Experiment, Section 3.2.1, Step 11.

   The remaining fields, representing the core module and optional modules will be greyed out, because they represent the installed hardware in the group. They become available if the Custom option is selected for the Instrument Group to use. This option enables *projects* to be transported between different ModuLab XM systems regardless of the installed hardware, but an *experiment* cannot be run until a specific *instrument group* has been selected.

   The Instrument Group to use field defaults to Custom if no group is available that is capable of performing the experiment.

   If you select an Experiment type and Instrument configuration that requires some optional modules, and then select an Instrument Group to use that does not have the modules fitted, a red error icon will appear alongside the module fields. The *experiment* will not run until the error is corrected.

6. Select an entry from the Grounding list box. The options are:

   Internal — The ModuLab XM system is internally grounded (LO connected to ground). This option should only be used if the sample is not grounded.

   External — The ModuLab XM system is externally grounded through the sample (LO floating). This option should only be used if the sample is grounded.

   NOTE: The LO point is a common reference voltage for modules within a group. For details see the Installation Guide.

   An amber warning icon will appear if the selected grounding is inappropriate for the *experiment*.

7. After setting up the Hardware Requirements, expand the additional sub-screens using the arrow button and fill in the fields if necessary to specify the detailed configuration of the *experiment*. The additional sub-screens are:

   ☞ Sample Setup, Section 5.3.3.

   ☞ Instrument Experiment Setup, Section 5.3.4.

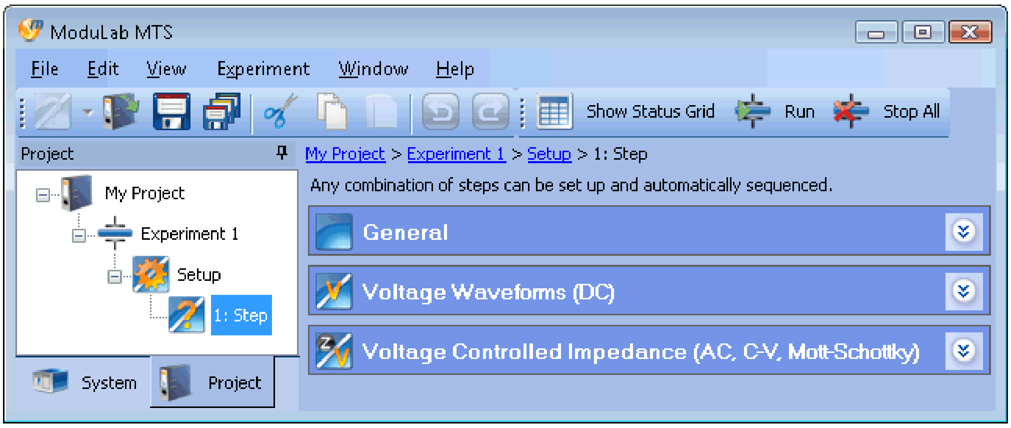
   ☞ Experiment Limits, Section 5.3.5.

3.2.3 Set up the Step

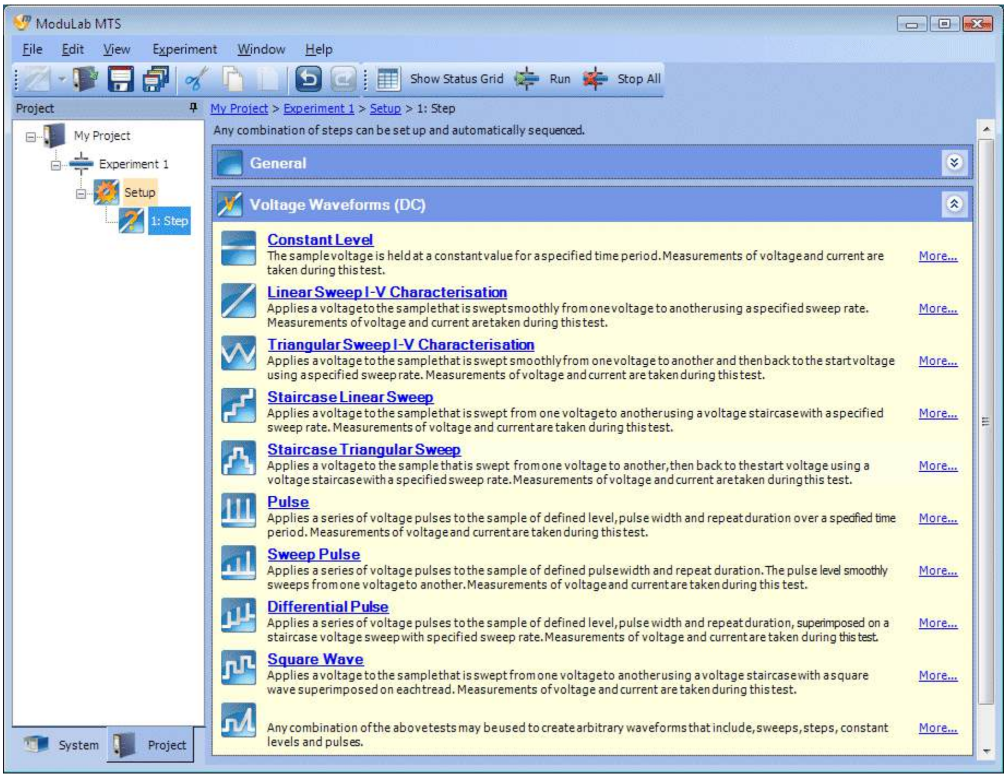
After setting up the *experiment*, which includes a single undefined *step* by default, you will need to set up the *step* to apply a stimulus to the sample and take the required measurements. A number of *step types* are available, including linear sweep, triangular sweep, etc., but for the purpose of this example we will configure the *step* to perform a linear DC voltage sweep.

☞ Step Types, Section 5.8.

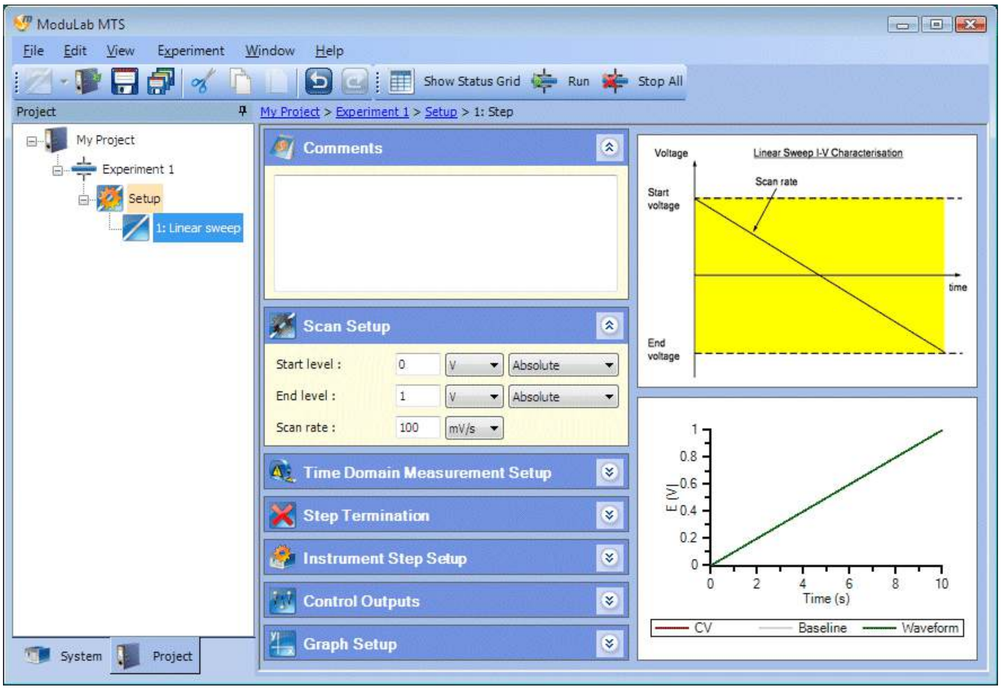
1. Click on the *step*, in the left-hand navigation panel, and a list of *step* categories will appear as follows:



2. Expand the Voltage Waveforms (DC) sub-screen to display the list of *step types* in this category as follows:



3. Click on Linear Sweep I-V Characterisation to display a set of configuration screens for this *step type* as follows:



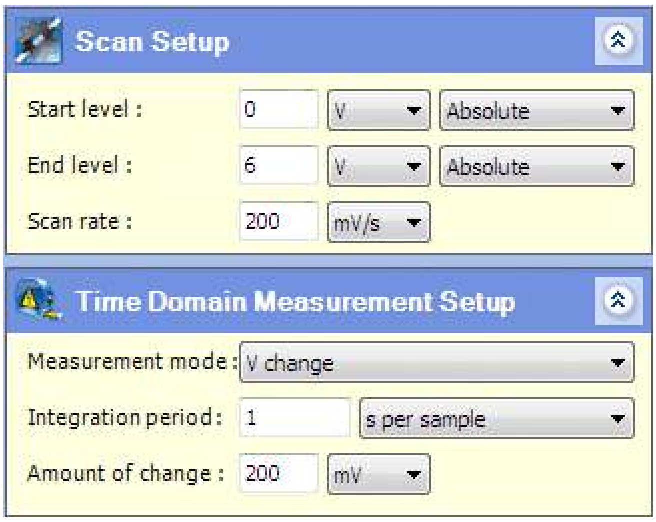
The item called Step, in the navigation panel, has changed to Linear Sweep. The sub-screens in the central column are for configuration of the *step*, and the two graphs on the right are for illustration and setup purposes as follows:

- The upper graph is a general representation of the waveform and explains the meaning of the parameters in the setup.
- The lower graph shows the waveform that will actually be applied to the sample, and will change when the values of the parameters are modified.

4. In the Scan Setup screen, make sure the Start level is at its default value of 0V and set the End level to 6V and the Scan rate to 200mV/s, and, so the screen is as follows:

This will give a duration of half a minute for the scan, and the time axis on the lower graph will be updated next time you click on a field (or on the graph itself).

5. Expand the Time Domain Measurement Setup sub-screen so it appears below the Scan Setup sub-screen. Make sure the Measurement mode is set to V change (to follow the voltage scan), and set the Integration period to 1 second per sample and the Amount of change to 200mV, so the screen is as follows:



In this example, the Scan rate is 200 mV/s and the Amount of change specifies that a measurement occurs after every 200mV of signal change, so there is 1 measurement per second. Data collected by the system is integrated to filter out noise, and the amount of filtering is defined by the Integration period, so that a short period follows the waveform more precisely but a long period filters out more noise.

The Integration period should not exceed the interval between measurements, and if it does, the system will use the interval between measurements as a maximum value. In this case, the Integration period has been set to 1 second to match the interval between measurements.

6. If necessary, expand the remaining sub-screens and edit the fields as described in the various sub-sections under the Step Setup. However, for the purpose of this *experiment*, it will be sufficient to leave these sub-screens at their default values.

☞ Step Setup, Section 5.7.

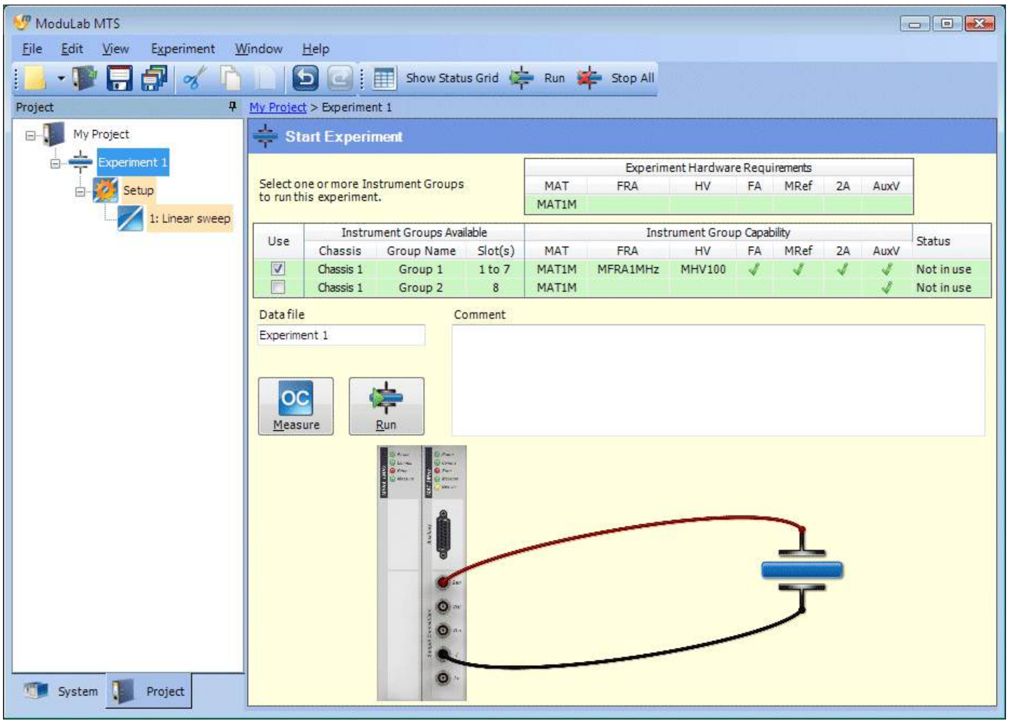
3.2.4 Connect the Hardware and Run the Experiment

You can connect the ModuLab XM MTS system to the sample at any stage while setting up the *experiment* from the software, as soon as you have displayed the appropriate connection diagram (by selecting the Experiment type and Instrument configuration in the Hardware Requirements sub-screen).

☞ Set up the Experiment, Section 3.2.2, and Hardware Requirements, Section 5.3.2.

The connection diagram is displayed on the Start Experiment screen, so you can check the connections and then run the *experiment* as follows:

1. Click on the *experiment* to display the Start Experiment screen:



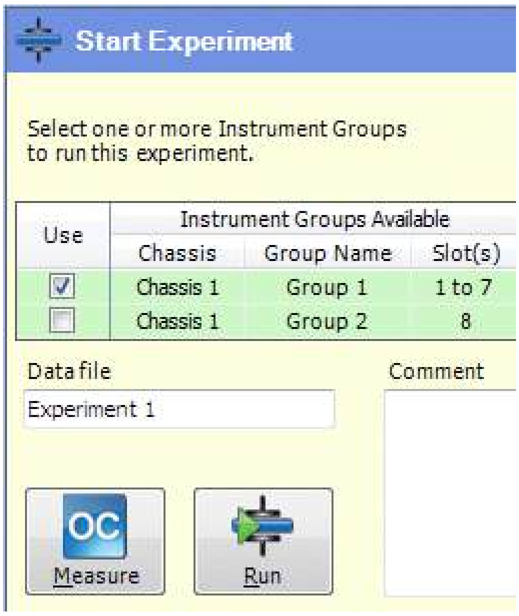
2. Make sure the Use box has become checked, for the *instrument group* to be used in this experiment, and all other boxes are cleared. Any group could be used, provided that it meets the Experiment Hardware Requirements (indicated by a green row in the tabulated list of groups). However, the default group is the one that was selected in the Instrument Group to use field, in the Hardware Requirements sub-screen, and this is the one we will use in this experiment.

   ☞ Hardware Requirements sub-screen, Section 3.2.2, Step 3.

3. Connect the ModuLab XM system to the sample using the appropriate cables.

   WARNING: In some circumstances it may be useful to connect the ModuLab XM Test Unit first (or the ModuLab XM 0.1 Ω Unit for high power applications) and do a dummy run of the *experiment*, before connecting the system to a real material sample. However, the primary purpose of the Test Unit is to test the modules under conditions of safety, and it does not represent the characteristics of material samples, which may vary greatly from each other. Do not rely on the Test Unit as an alternative to carefully checking the characteristics of your system.

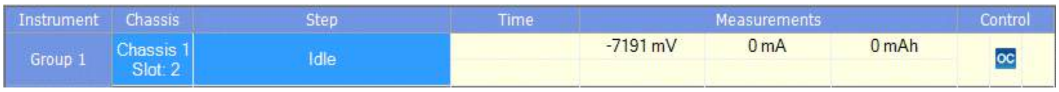
4. If you like, you can type a name in the Data file field, but for the purpose of this example we will leave it at its default, which is the same as the *experiment* name.



5. If you like, you can perform an open circuit measurement, to see how the sample will perform without applying an excitation signal from the generator, otherwise go to Step 7. To perform an open circuit measurement, click the OC Measure button to display the Status Grid as follows:

An Open Circuit *step* appears in the Status Grid and the results in the Measurements column will be updated as the measurements are taken.

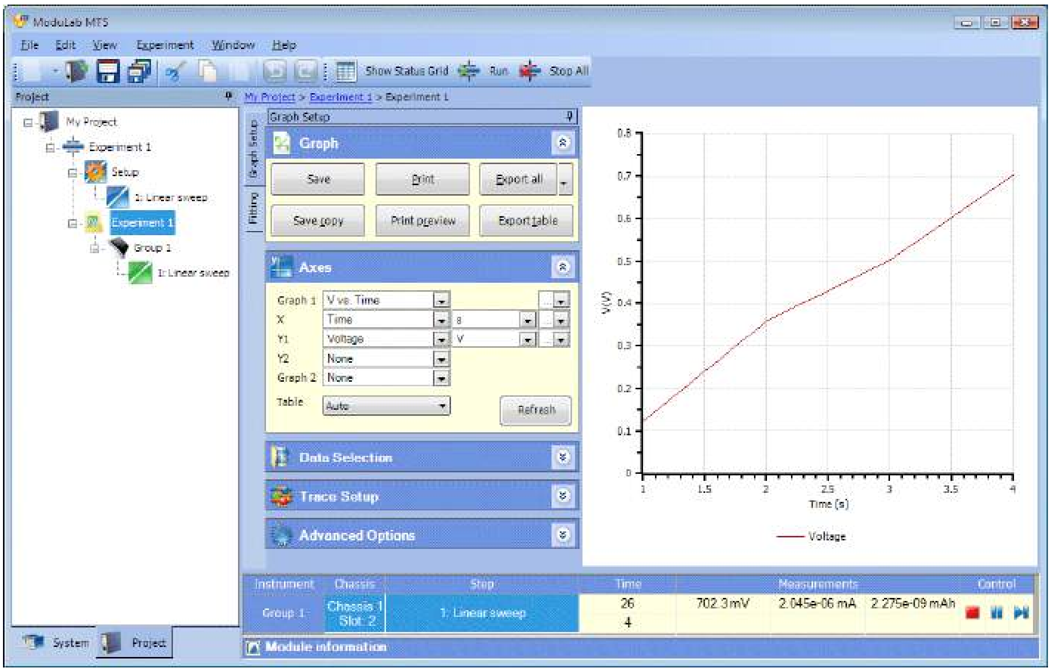
6. Click the red control button at the right of the Status Grid to stop the Open Circuit *experiment*. The status will change to Idle and the measurements will stop animating. The Status Grid will be as follows:



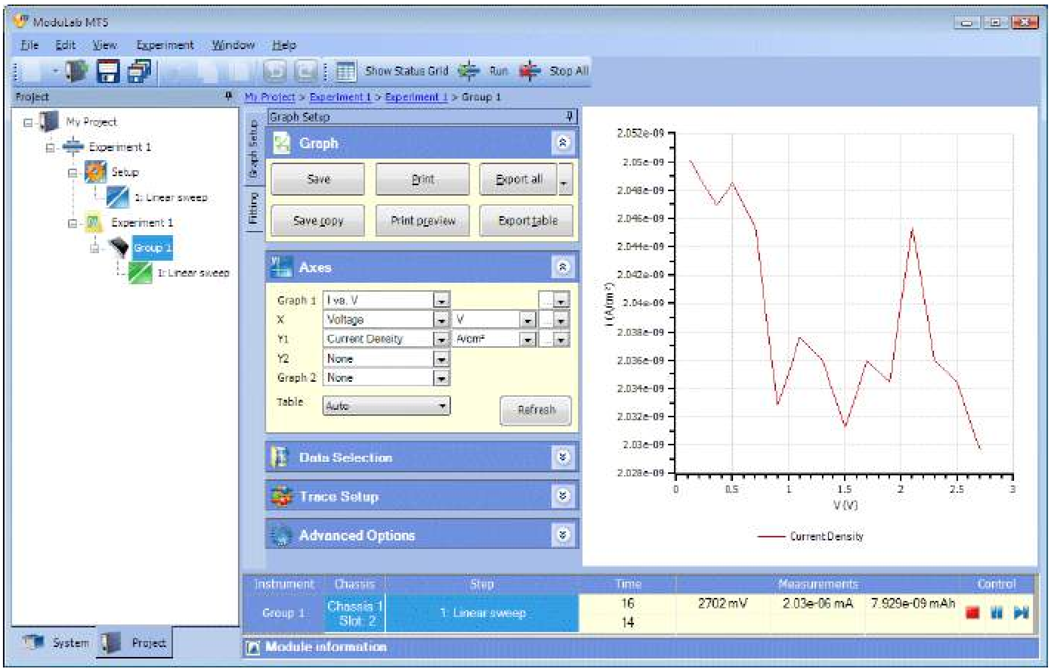
The red control button has disappeared and an OC button has appeared. This is the same as the OC Measure button in the Start Experiment screen, and re-starts the Open Circuit measurements.

7. Click the Run button to run the *experiment*, and a Data File item will appear in the navigation panel, under the *experiment*, and will automatically be expanded to show the sub-items.

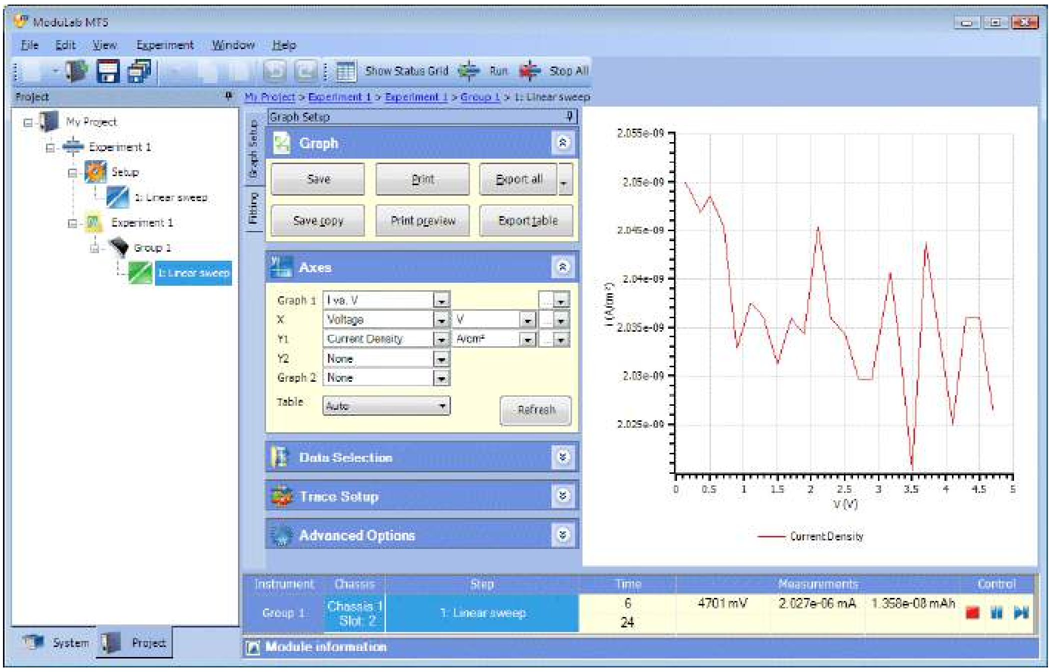
8. While the *experiment* is running, click the Data File item to display a graph, which is updated as each new measurement is taken. This graph gives an overview of the data for the *experiment*, in terms of voltage against time, as follows:



9. While the *experiment* is still running, click the item for the *instrument group*. This will display the data for the *step* that is currently running on this core module, in terms of current density against voltage, as follows:

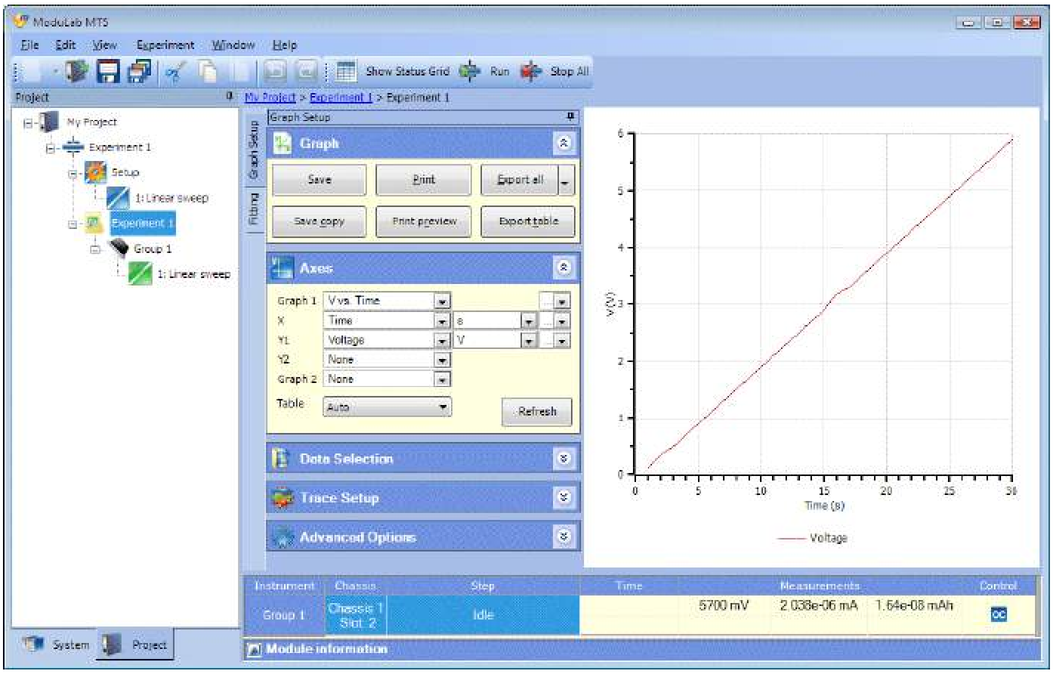


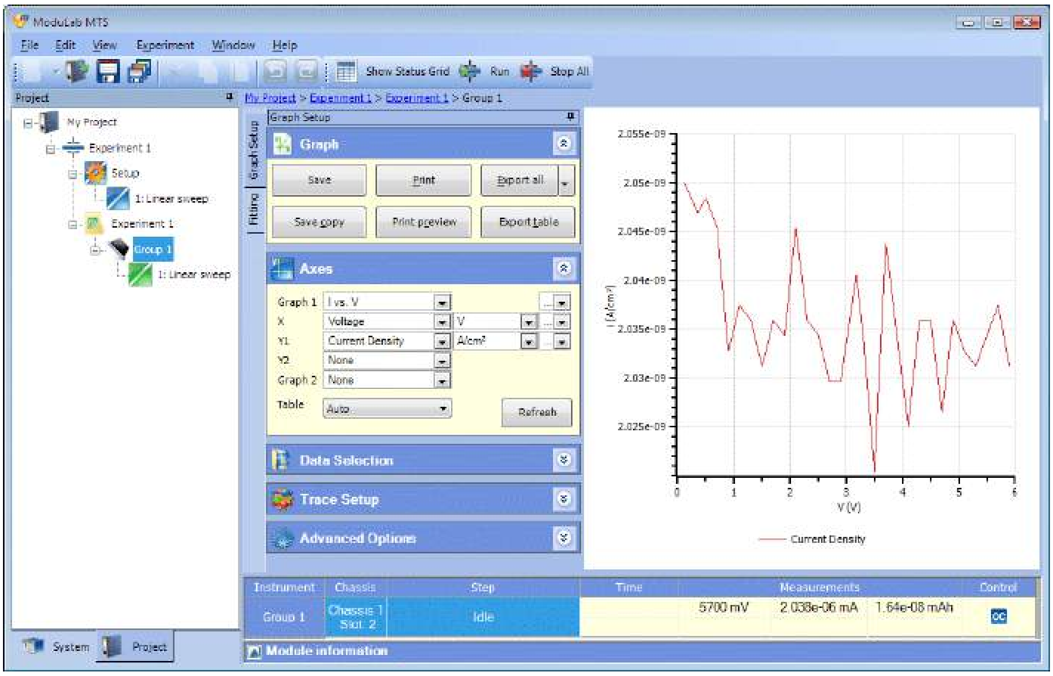
10. While the *experiment* is still running, click on the *step* (in this case Linear Sweep) so that it shows the data for the *step* as follows:

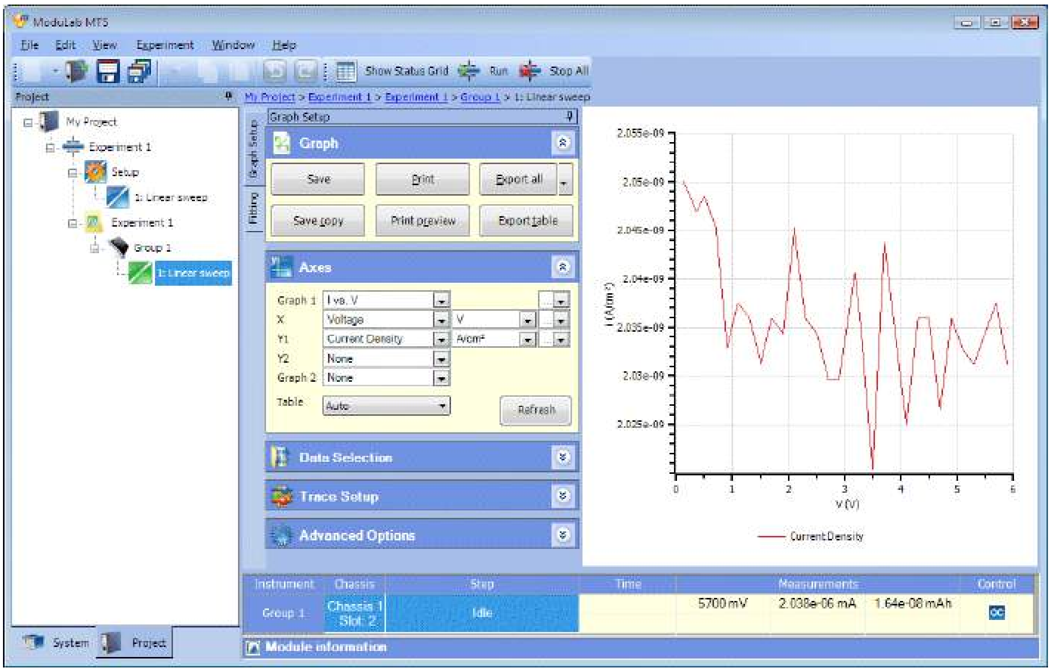


The data will continue to be updated while the *experiment* is running, until it is complete.

11. Click again on the three items in the navigation panel to display the completed results as follows:







Now that we have observed these three displays of results, both during and after the *experiment*, they can be summarised as follows:

- The Experiment 1 screen gives a graph of voltage against time for the *experiment* as a whole.
- The Group 1 screen gives the results that are currently being collected by this core module, while the *experiment* is running. The results correspond to the current *step*, and are displayed in terms of current density against voltage because these are the axes used by the *step*. When the *experiment* has been completed, the graph changes to voltage against time, because it represents the core module more generally, without any specific reference to a *step*, and

since there is only one core module, the graph is the same as in the Data File screen.

- The Linear Sweep screen gives the data for the *step*, and the graph axes represent current density against voltage (I vs. V) which is the default for this *step type*, specified in the Graph Preferences.

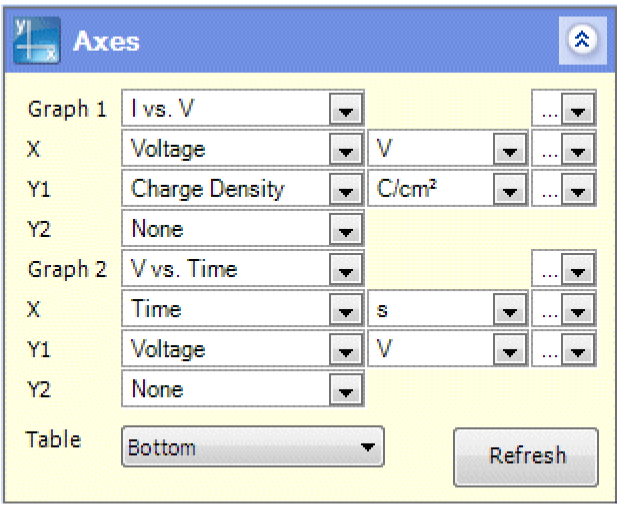
  ☞ Step 7, Section 3.2.1.

NOTE: The Group 1 item is only temporary in systems that have only one core module, and it exists for the purpose of displaying the results of a sequence of *steps* while the *experiment* is in progress. If you close the *project* after the *experiment* is complete, and re-open it again, the Group 1 item will not be present and the Linear Sweep *step* will appear immediately under the Data File. However, the *instrument group* items remain permanently in the structure in systems that have more than one core module.

3.2.5 Display Graphs and Tables

In this example so far, we have displayed a single graph on each screen of results. However, you can change the axes to display different data, or you can display a second graph, or a tabulated list of data. Here is an example of how to change the display by editing the Axes sub-screen:

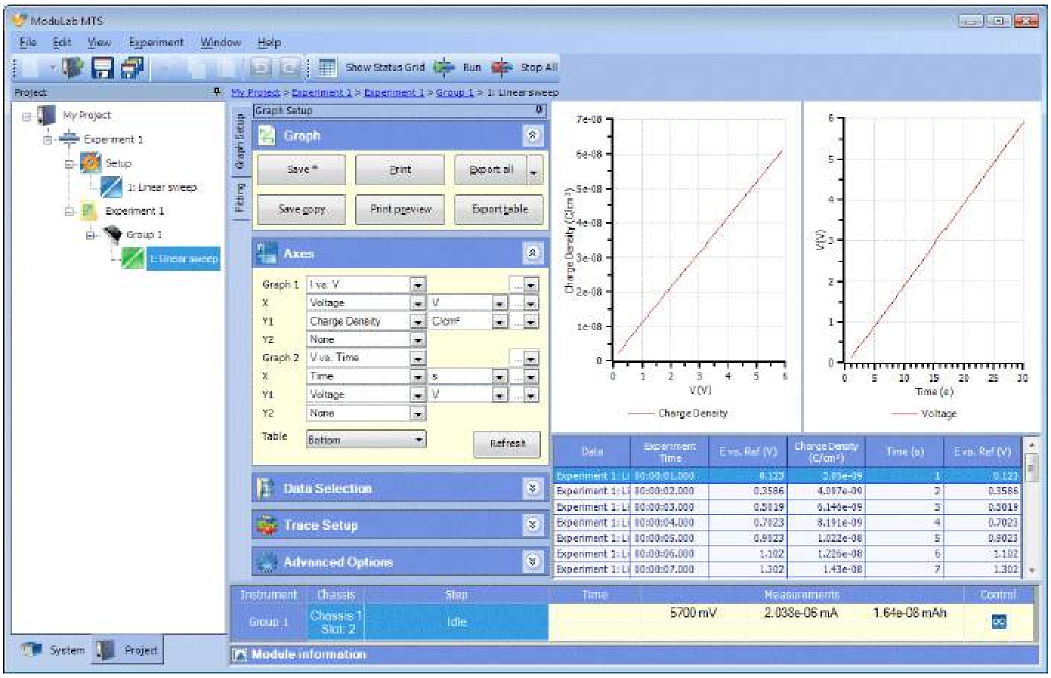
1. Make sure the *step* (in this case Linear Sweep) is selected in the data file structure in the navigation panel, to display the results for the *step*.
2. In the Axes sub-screen, select Charge Density in the Y1 list box.
3. In the Graph 2 list box, select V vs. Time. The sub-screen will expand to show the axis fields for the second graph, but you can leave them at their default values.
4. In the Table list box, select Bottom. The sub-screen will be as follows:



☞ Axes, Section 5.10.2.

5. Click the Refresh button, if required, to re-display the data. This will only be needed if an amber warning icon appears alongside the button. The display is

automatically refreshed when the Table field is changed, and the screen will be as follows:



This display contains two graphs and a tabulated list of results with columns that include the data displayed in the graphs. There are various ways of processing the results of *experiments*, including manipulation of graphs, import and export of data between *experiments*, and exchange of data between users of different systems

☞ Data, Section 5.10, and Graphs, Section 5.11.

3.2.6 Add an AC Step and repeat the Experiment

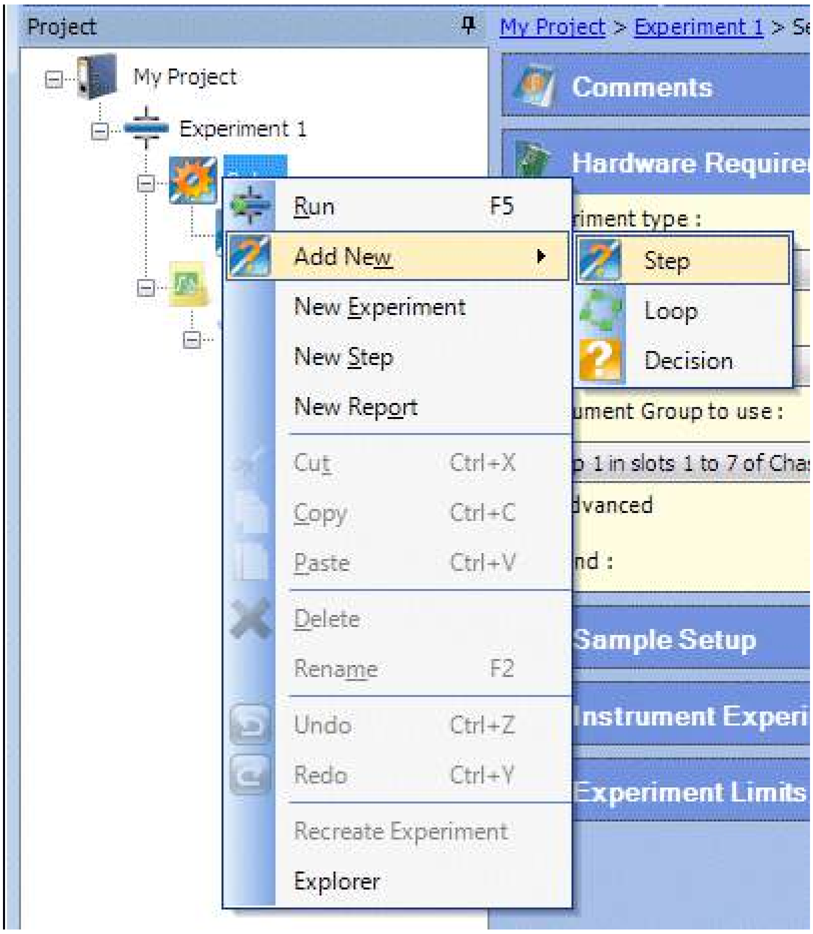
Now that we have run the *experiment* with a DC *step* (by configuring the *step* that was included in the *experiment* by default), we will add a new AC *step* to perform impedance measurements. To run an *experiment* with AC *steps*, a frequency response analyzer has to be installed for use with the core module.

A variety of AC *step types* are available, but for the purposes of this example, we will use Constant Level Impedance. In this *step type*, a constant DC voltage is applied to the sample, while a frequency sweep is superimposed on it.

☞ Step Types, Section 5.8.

To add the AC *step* and repeat the *experiment*, proceed as follows:

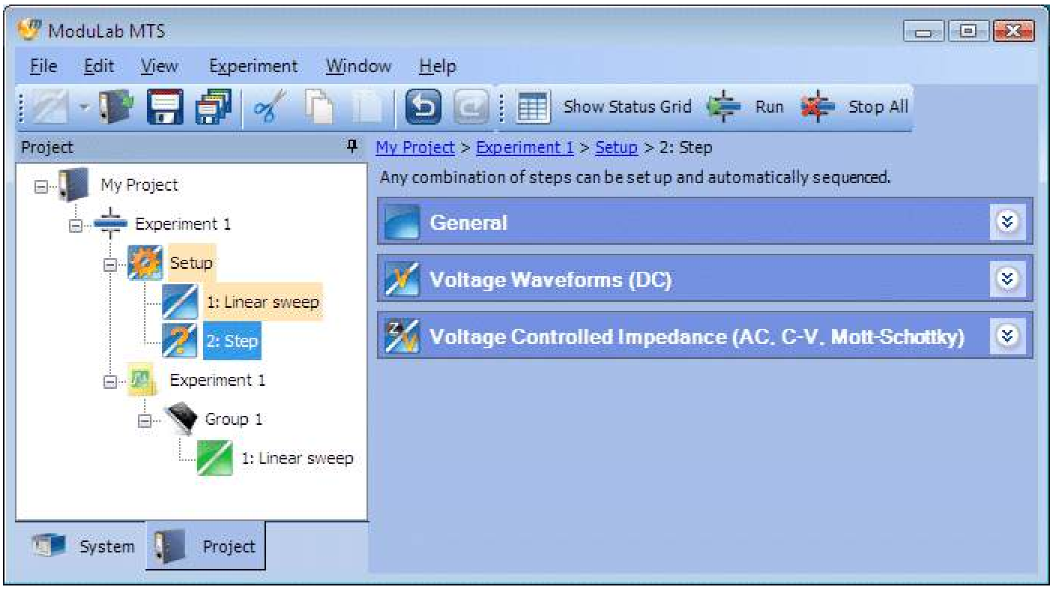
1. Right-click on the Setup item, under the *Experiment*, to display the drop-down list box and hold the cursor over Add New, then select Step as follows:



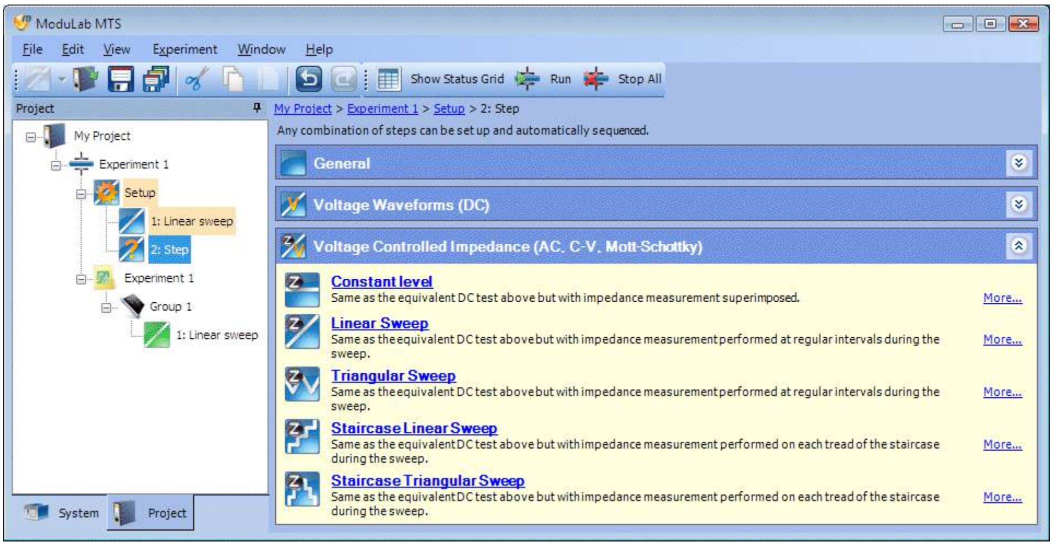
NOTE: You could use New Step instead of Add New and then Step, and it would make no difference in this case, although the two commands are functionally different.

☞ Add New, Section 2.4.1 and New Step, Section 2.4.4.

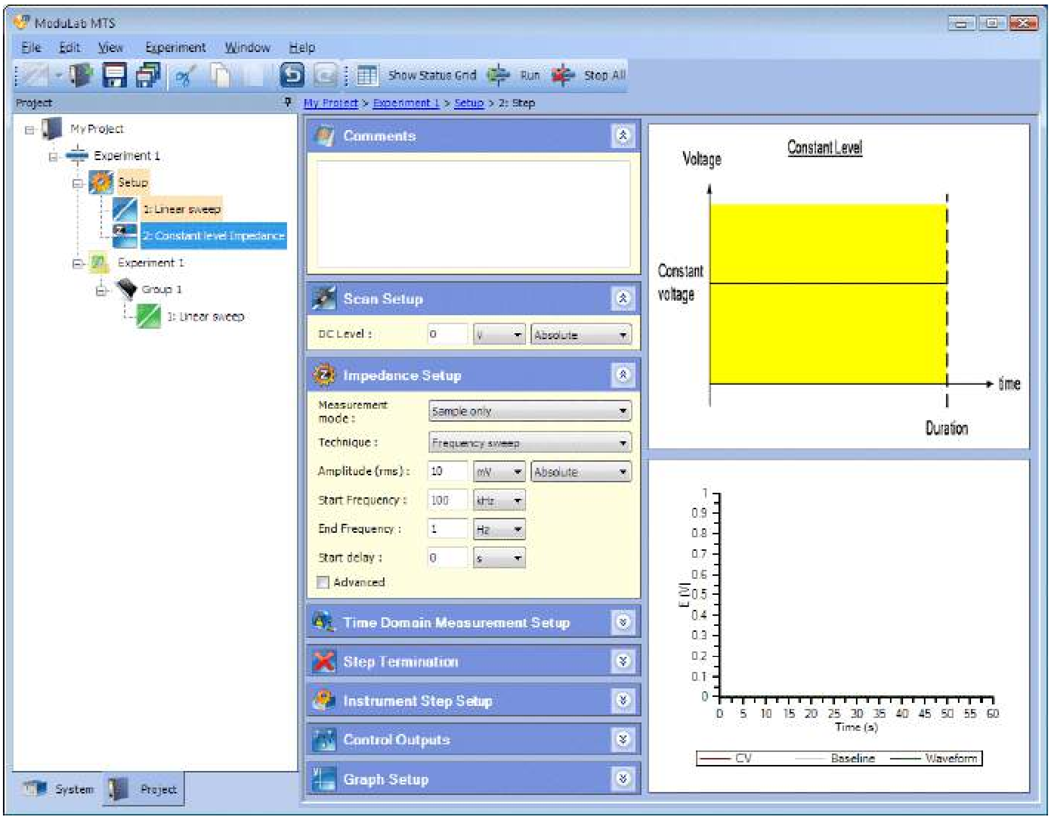
A list of *step* categories will appear as follows:



2. Expand the Voltage Controlled Impedance sub-screen to display the list of *step types* in this category as follows:



3. Select Constant Level. The item called Step, in the navigation panel, will change to Constant Level Impedance, and the display will be as follows:



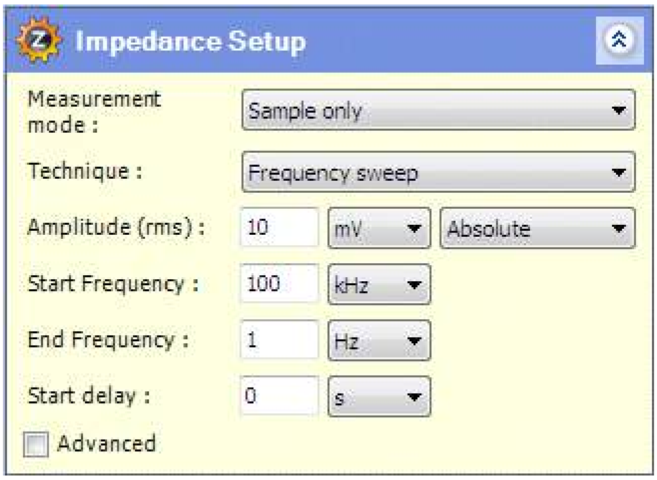
The sub-screens in the central column of this display are the same as for the DC *step*, except for the following:

- The Scan Setup sub-screen has a single field to specify a Level for the constant DC voltage to be applied to the sample.
- There is an additional sub-screen for Impedance Setup, to specify what sort of alternating signal is to be superimposed on the DC voltage.
- The Time Domain Measurement Setup sub-screen is limited to periodic measurements, because there is no voltage change on which to base the measurement rate.

4. Specify an appropriate Level in the Scan Setup sub-screen. If you like, you can leave it at its default value of zero, as follows:

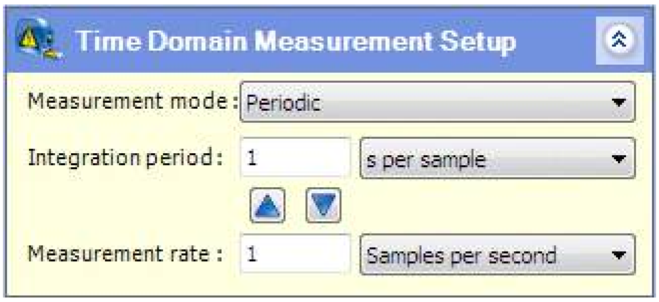
☞ Scan Setup for Constant Level Impedance, Section 5.8.4.6.

5. Fill in the Impedance Setup with appropriate values. If you like, you can leave it at its default values as follows:



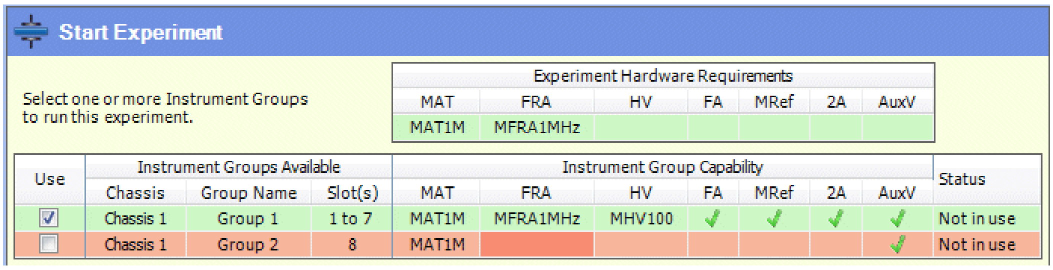
☞ Impedance Setup, Section 5.7.1.

6. Expand the Time Domain Measurement Setup sub-screen and fill it in with appropriate values. If you like, you can leave it at its default values as follows:



☞ Time Domain Measurement Setup, Section 5.7.2.

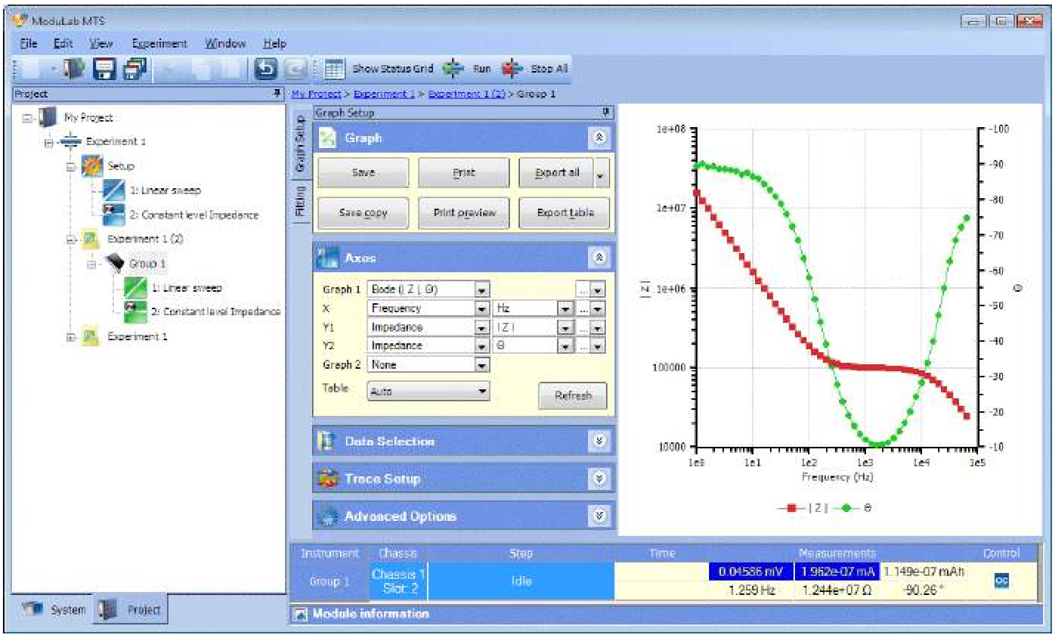
7. Continue with the instructions for the DC experiment and you will find that in the tabulated list of hardware, in the Start Experiment screen, the FRA will appear in the list of Experiment Hardware Requirements as follows:



NOTE: In the Instrument Group Capability, the row representing Group 2 has turned red, indicating that it is unsuitable for use with this *experiment*. The column representing the FRA has turned a darker shade of red, indicating that this is the reason why the *group* cannot be used. It does not have an FRA, so it cannot carry out the impedance *step*.

When you run the *experiment*, the *steps* will run successively, first the Linear Sweep, then the Constant Level Impedance. When the *data* item appears for

Constant Level Impedance, you will be able to click on it and watch the graphs being drawn. These will depend on the User Preferences, but there will normally be a single Bode plot of impedance magnitude and phase angle against frequency as follows:



You will be able to display other AC plots by editing the Axes sub-screen.

☞ Display Graphs and Tables, Section 3.2.5, and Axes, Section 5.10.2.

3.3 HARDWARE AND CONNECTION CONFIGURATIONS

The hardware and connection configurations used by the ModuLab XM MTS system fall into the following categories:

☞ Normal (Section 3.3.2)

☞ Sample and Reference (Section 3.3.3).

☞ Installation Test (Getting Started Guide and Installation Guide)

Each of the sub-sections, under these main headings, describes one of the pre-defined hardware and connection configurations (except for the Installation Test). The configuration for General Materials Testing is described first as an example, giving a brief outline of how to set up and run an *experiment*.

☞ Example: General Materials Testing, Section 3.3.1.

The remaining *experiments* are the same, except for the following:

- In the ModuLab XM MTS software, you have to select the required experiment type and instrument configuration, to display the appropriate connection diagram.
- You have to connect the modules to the test sample according to the displayed diagram.

Steps may be added to *experiments* as follows:

- For time domain analysis, use any *step type* under Voltage Waveforms (DC).

  ☞ Section 5.8.2.

- For impedance analysis, use any *step type* under Voltage Controlled Impedance, at the required DC voltage level. Impedance tests require an FRA module to be fitted.

  ☞ Section 5.8.3.

The ModuLab XM system may be grounded internally or externally, depending on the grounding of the sample.

- If the sample is not grounded, the ModuLab XM system must be grounded internally (LO grounded) .
- If the sample is grounded, the ModuLab XM system must be grounded externally (LO floating).

☞ The LO point is a common reference voltage for modules within an *instrument group*. For details see the Installation Guide.

3.3.1 Example: General Materials Testing

This configuration is used for general purpose tests on a wide range of materials The materials core module is used to control the DC conditions on the sample and a frequency response analyzer may be added if impedance measurements are required. This configuration is suited to testing samples that do not require extremely high or low voltage / current measurements. Samples can be tested over a ±8V range with current levels up to ±100mA, which is sufficient for many types of materials.

To set up an *experiment* with this configuration:

1. Run the ModuLab XM software and set up an *experiment*.

   ☞ Set up the Experiment, Section 3.2.2.

   In the Hardware Requirements sub-screen, make the following selections from the list boxes:

Experiment Type:	Normal
Instrument configuration:	Mat only

   A connection diagram will appear as shown in Figure 3-1.

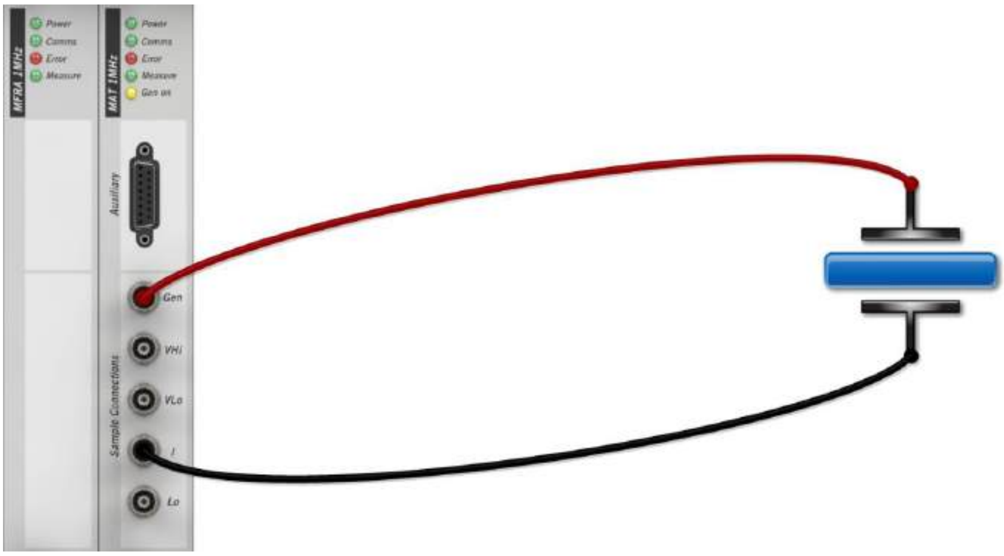


Figure 3-1 General materials testing

2. Review the values in the *experiment* setup, and change them if necessary, so that they are compatible with the characteristics of the material.

   ☞ Experiment Setup, Section 5.3.

3. Add some *steps* and *loops*, or change the existing *steps* and *loops*, making sure that the values in the dialogue boxes are compatible with the characteristics of the material.

   ☞ Step, Section 5.6, and Loop, Section 5.4.

WARNING: Always check the characteristics of the material, and set up the ModuLab XM system accordingly, to ensure safe operation of the *experiment*. You can do a dummy run first, using the Dielectric Reference Module, but in most circumstances this will not predict the response of real material samples which may have entirely different characteristics.

4. Connect the core module to the sample using the appropriate cables, as shown in Figure 3-1.
5. Run the *experiment* and review the results.

   ☞ Section 3.2.4.

NOTE: These instructions apply specifically to this *experiment*. If you are running one of the other *experiments*, make the appropriate selections from the ModuLab XM software and use the corresponding connection diagram.

3.3.2 Normal Experiment Type

The *experiment* configurations in the Normal category are used for a wide range of applications, including:

- High voltage experiments, for example when testing dielectrics, insulators, ceramics and display panel materials,
- High impedance experiments, for example nanotechnology and insulator tests.
- High power experiments involving, for example, high conductivity materials and superconductors.

The configurations are:

☞ General Materials Testing, Section 3.3.2.1 (example, Section 3.3.1)

☞ High Voltage, Section 3.3.2.2

☞ High Impedance, Section 3.3.2.3

☞ High Voltage / High Impedance, Section 3.3.2.4

☞ Low Voltage with Booster, Section 3.3.2.5

☞ High Voltage with Booster, Section 3.3.2.6

3.3.2.1 General Materials Testing

This configuration is used for general purpose tests on a wide range of materials.

To access this configuration and display the connection diagram, select the following entries from the Hardware Requirements sub-screen (Section 5.3.2)	
Experiment Type:	Normal
Instrument configuration:	Mat only

☞ Details of this configuration are given in the example, Section 3.3.1.

3.3.2.2 High Voltage Materials Testing

This configuration is used for testing materials that require high stimulus voltage and/or measurement of high voltage signals. The MHV 100 module is used, producing a voltage up to 100V.

WARNING: Take care to use this module so that the voltage output does not constitute a safety hazard. See the General Safety Precautions at the beginning of this manual.

Typical examples where the high voltage module may be required are testing dielectrics, insulators, ceramics and display panel materials.

To access this configuration and display the connection diagram, select the following entries from the Hardware Requirements sub-screen (Section 5.3.2)	
Experiment Type:	Normal
Instrument configuration:	Mat + HV

A connection diagram will appear as shown in Figure 3-2.

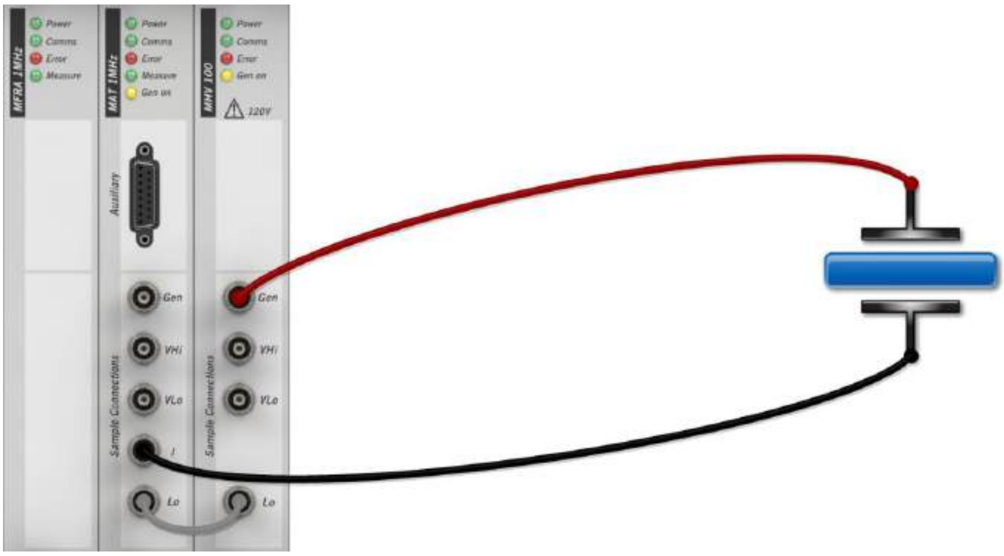


Figure 3-2 High voltage system

For some applications, higher current levels may be required and this can be accomplished by adding a booster to this configuration.

☞ High Voltage with Booster, Section 3.3.2.6

3.3.2.3 High Impedance Materials Testing

This configuration combines the materials core module with a highly sensitive current to voltage converter (femto ammeter) module. This includes all of the ranges of the standard core module, so it can measure up to ±100mA, but provides additional ranges at the low current end for measuring femto amps (10^{-15} amps) or less.

The femto ammeter may be required, for example, in nanotechnology or the measurement of very high resistance samples such as insulators.

The characteristics of this configuration is mid-range voltage / current stimulus but with current measurement into the femto-amp range.

To access this configuration and display the connection diagram, select the following entries from the Hardware Requirements sub-screen (Section 5.3.2)	
Experiment Type:	Normal
Instrument configuration:	MAT + Femto Ammeter

A connection diagram will appear as shown in Figure 3-3.

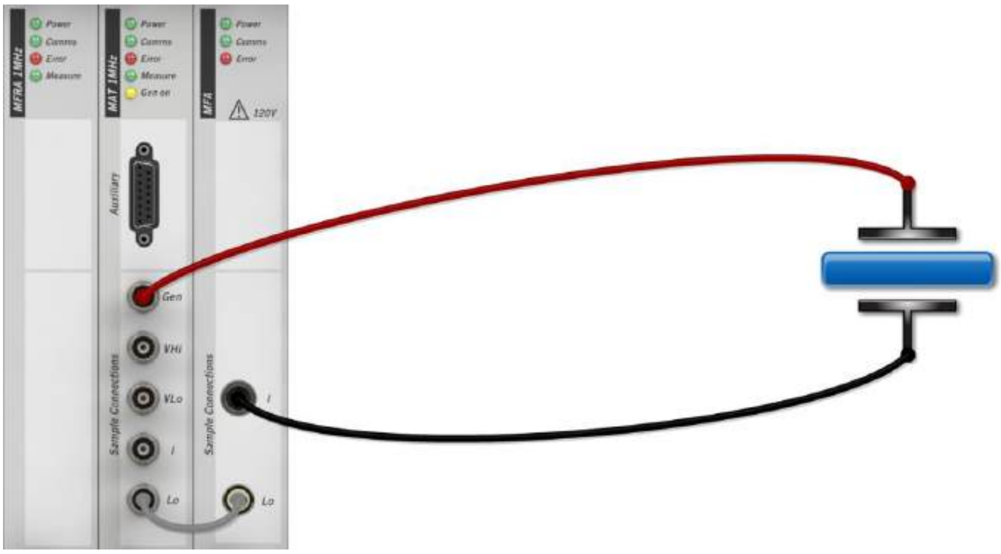


Figure 3-3 High impedance system

3.3.2.4 High Voltage / High Impedance Materials Testing

This provides a combination of high voltage, using the MHV 100 module, together with femto amp current resolution using the femto ammeter module. This is very useful for tests where the sample has very high resistance.

This configuration may be required, for example, in nanotechnology or the measurement of very high resistance samples such as insulators.

A high voltage is required to drive the sample, but the resulting current, due to the high resistance of the sample, is very low.

WARNING: The current return to the femto ammeter can have a voltage of up to 100V if the sample is excited by a high voltage module. Take care to use these modules so that they do not constitute an electrical safety hazard. See the General Safety Precautions at the beginning of this manual.

To access this configuration and display the connection diagram, select the following entries from the Hardware Requirements sub-screen (Section 5.3.2)	
Experiment Type:	Normal
Instrument configuration:	Mat + HV + Femto Ammeter

A connection diagram will appear as shown in Figure 3-4.

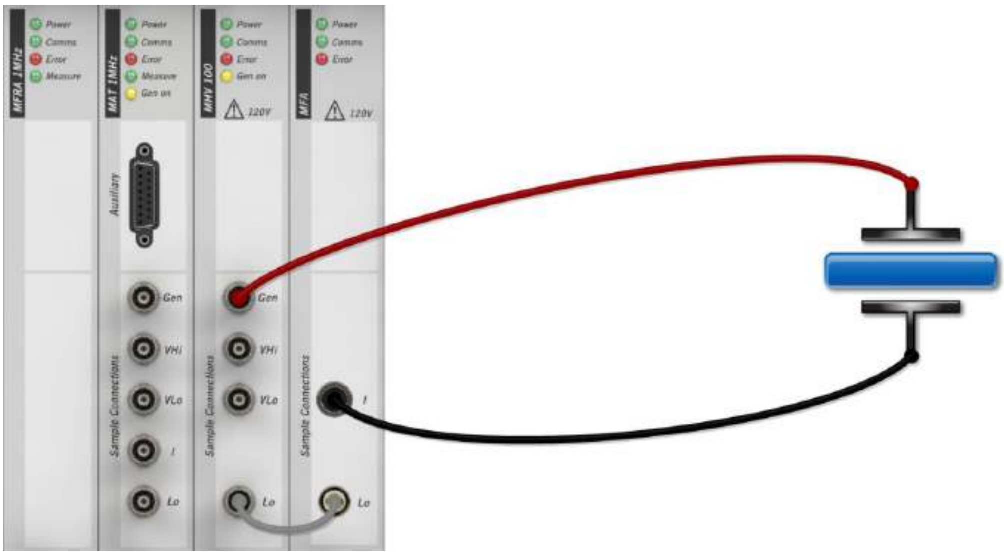


Figure 3-4 High voltage / high impedance system

3.3.2.5 Low Voltage with Booster

In this configuration, the materials core module and booster are configured to test material samples at high power and low voltage (±2A, ±8V). The core module is connected to the booster, and the booster is connected to the sample.

The booster may be required, for example, for testing high conductivity materials and superconductors.

To access this configuration and display the connection diagram, select the following entries from the Hardware Requirements sub-screen (Section 5.3.2)	
Experiment Type:	Normal
Instrument configuration:	Mat + 2A

A connection diagram will appear as shown in Figure 3-5.

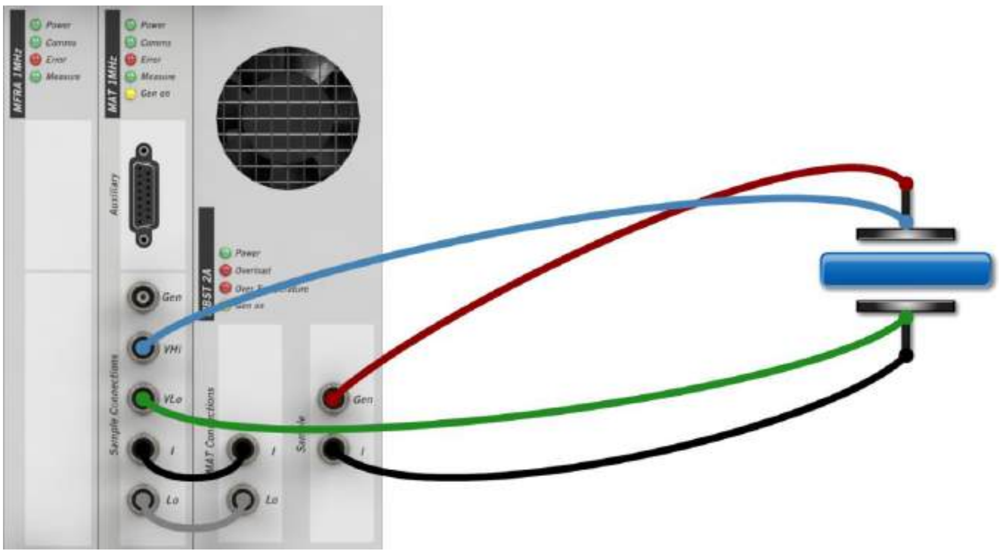


Figure 3-5 Low voltage system with booster

NOTE: The booster requires 4 Terminal connections to be specified in the Instrument Experiment Setup, because voltage measurements from Vhi and VLo are required for low impedance samples. An error message will appear in the Start Experiment screen if 2 Terminal connections are specified.

☞ Section 5.3.4, Instrument Experiment Setup.

☞ Section 5.2.2, Start Experiment.

3.3.2.6 High Voltage with Booster

In this configuration, the materials core module, high voltage module and booster are configured to test the sample at high power and high voltage (±2A, ±20V). The core module is connected to the booster and the booster is connected to the sample. The voltage measurement electrodes are connected to the high voltage module (not the core module) because high voltages are present in the sample.

This configuration may be required, for example, for testing high conductivity materials and superconductors.

To access this configuration and display the connection diagram, select the following entries from the Hardware Requirements sub-screen (Section 5.3.2)	
Experiment Type:	Normal
Instrument configuration:	Mat + HV + 2A

A connection diagram will appear as shown in Figure 3-6.

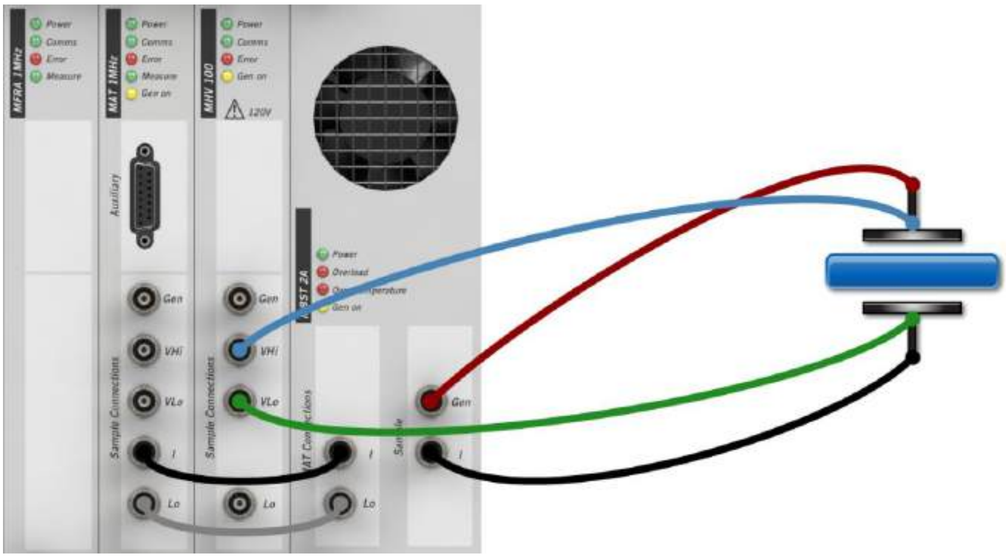


Figure 3-6 High voltage system with booster

NOTE: The booster requires 4 Terminal connections to be specified in the Instrument Experiment Setup.

☞ Section 5.3.4, Instrument Experiment Setup.

3.3.3 Sample and Reference

The sample and reference module (MREF) reduces cable capacitance effects that may occur during impedance *steps*, by comparing the capacitance of the sample with known reference capacitors. This optional module can be used in combination with other modules in the *instrument group*, so that the circuit connections to the sample are modified as follows:

- The cables that would otherwise connect to the Hi and Lo electrodes on the sample are instead connected to the Gen and I connectors on the Sample and Reference module.
- The Hi and Lo Smp connectors on the Sample and Reference module are connected to the Hi and Lo electrodes on the sample.

The compensating capacitance is introduced internally or externally as follows:

- For internal referencing, the Hi and Lo Reference sockets on the Sample and Reference module are connected to their corresponding Hi and Lo Internal Reference sockets, using appropriate cables.
- For external referencing, the Hi and Lo Reference sockets are connected to the Hi and Lo electrodes of a known external capacitor, using appropriate cables.

In both cases, the cables used for referencing must be identical to the cables connecting to the sample, and of the same length.

The choice between internal and external referencing has to be specified in the ModuLab XM software, in the Sample Setup sub-screen, and the appropriate connections diagram will appear.

☞ Section 5.3.3, Sample Setup.

The specification of the Sample and Reference module for use in an *experiment* does not necessarily mean that it has to be used in all the impedance *steps*. The Measurement Mode in the Impedance Setup for each *step* can be set as follows:

Sample only	Measurements are taken from the sample without using the Sample and Reference module.
Sample & Reference	The Sample and Reference module is used according to the *experiment* Setup.

☞ Section 5.7.1, Impedance Setup.

The following additional considerations apply to the Sample and Reference module:

- Internal grounding should always be used because the internal reference capacitors cannot be externally grounded. A user reference capacitor could be externally grounded, but it would discharge and give no meaningful results. If the Experiment type in the Hardware Requirements sub-screen is set to Sample & Reference, and the Ground field is set to External, an amber warning icon will appear.

  ☞ Section 5.3.2, Hardware Requirements

- 2 Terminal connections are always used with the Sample and Reference module because the reference channels (Ref) are associated with the sample channels (Smp) and there is no referencing for the voltage measurement channels VHi and VLo. An error message will appear in the Start Experiment screen if 4 Terminal connections are specified in the Instrument Experiment Setup.

  ☞ Section 5.2.2, Start Experiment.

  ☞ Section 5.3.4, Instrument Experiment Setup.

- The 2A booster cannot be used with the Sample and Reference module because it requires 4 Terminal connections.

In the following sub-sections, the Sample and Reference module is used with various other modules, and the connection diagrams (Figures 3-7 to 3-10) show internal referencing, although external referencing could also be used.

3.3.3.1 General Materials Testing with Reference Capacitance

This configuration is used for general purpose impedance tests on a wide range of materials, where compensation is required for cable capacitance. A Sample and Reference module is used with a materials core module and an FRA.

To access this configuration and display the connection diagram, select the following entries from the Hardware Requirements sub-screen (Section 5.3.2)	
Experiment Type:	Sample & Reference
Instrument configuration:	Mat only

A connection diagram will appear as shown in Figure 3-7.

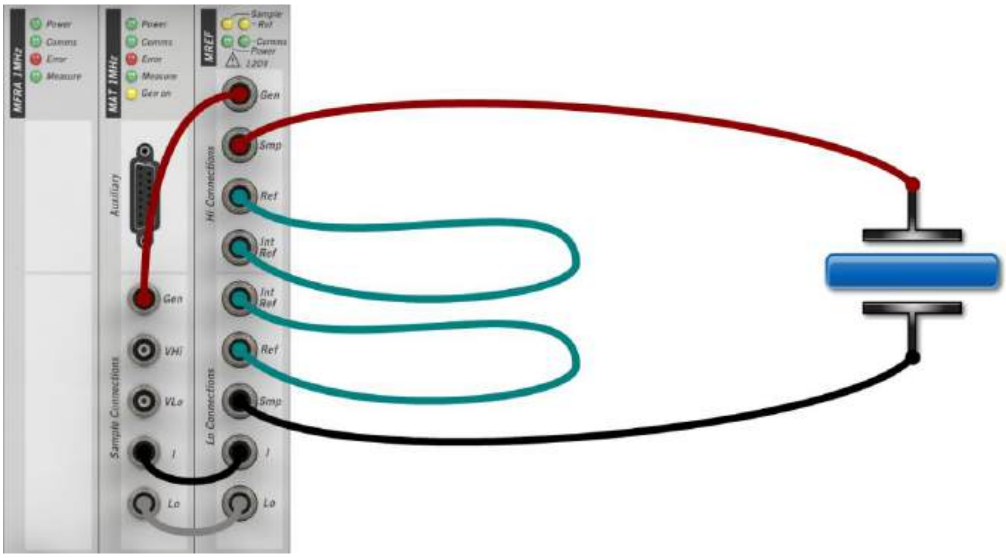


Figure 3-7 General materials testing with internal referencing

☞ In this configuration, the Sample and Reference module has been added to General Materials Testing, Section 3.3.1.

☞ The alternative connection diagram for external referencing is available by selecting User Reference in the Sample and Ref field, in the Sample Setup, Section 5.3.3.

3.3.3.2 High Voltage Testing with Reference Capacitance

This configuration is used for impedance testing of materials that require high stimulus voltage in circumstances where compensation is required for cable capacitance. A Sample and Reference module is used with a materials core module, a high voltage module and an FRA.

To access this configuration and display the connection diagram, select the following entries from the Hardware Requirements sub-screen (Section 5.3.2)	
Experiment Type:	Sample & Reference
Instrument configuration:	Mat + HV

A connection diagram will appear as shown in Figure 3-8.

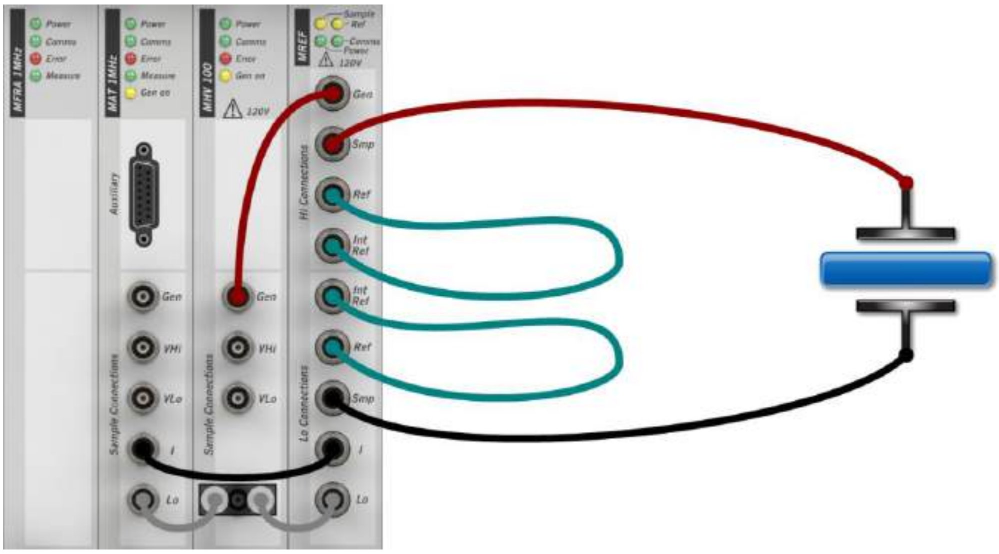


Figure 3-8 High voltage system with internal referencing

☞ In this configuration, the Sample and Reference module has been added to High Voltage Materials Testing, Section 3.3.2.2.

☞ The alternative connection diagram for external referencing is available by selecting User Reference in the Sample and Ref field, in the Sample Setup, Section 5.3.3.

3.3.3.3 High Impedance Testing with Reference Capacitance

This configuration is used for impedance testing of materials that pass very low currents in circumstances where compensation is required for cable capacitance. A Sample and Reference module is used with a materials core module, a femto ammeter and an FRA.

To access this configuration and display the connection diagram, select the following entries from the Hardware Requirements sub-screen (Section 5.3.2)	
Experiment Type:	Sample & Reference
Instrument configuration:	Mat + Femto Ammeter

A connection diagram will appear as shown in Figure 3-9.

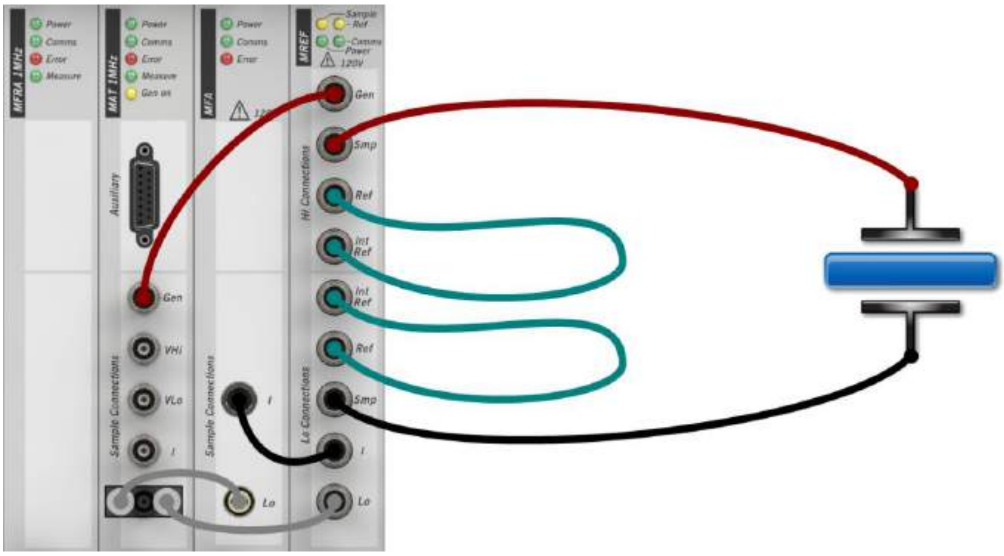


Figure 3-9 High impedance system with internal referencing

☞ In this configuration, the Sample and Reference module has been added to High Impedance Materials Testing, Section 3.3.2.3.

☞ The alternative connection diagram for external referencing is available by selecting User Reference in the Sample and Ref field, in the Sample Setup, Section 5.3.3.

3.3.3.4 High Voltage / High Impedance Testing with Reference Capacitance

This configuration is used for impedance testing of materials that pass very low currents at high voltage, in circumstances where compensation is required for cable capacitance. A Sample and Reference module is used with a materials core module, high voltage module, femto ammeter and an FRA.

To access this configuration and display the connection diagram, select the following entries from the Hardware Requirements sub-screen (Section 5.3.2)	
Experiment Type:	Sample & Reference
Instrument configuration:	Mat + HV + Femto Ammeter

A connection diagram will appear as shown in Figure 3-10.

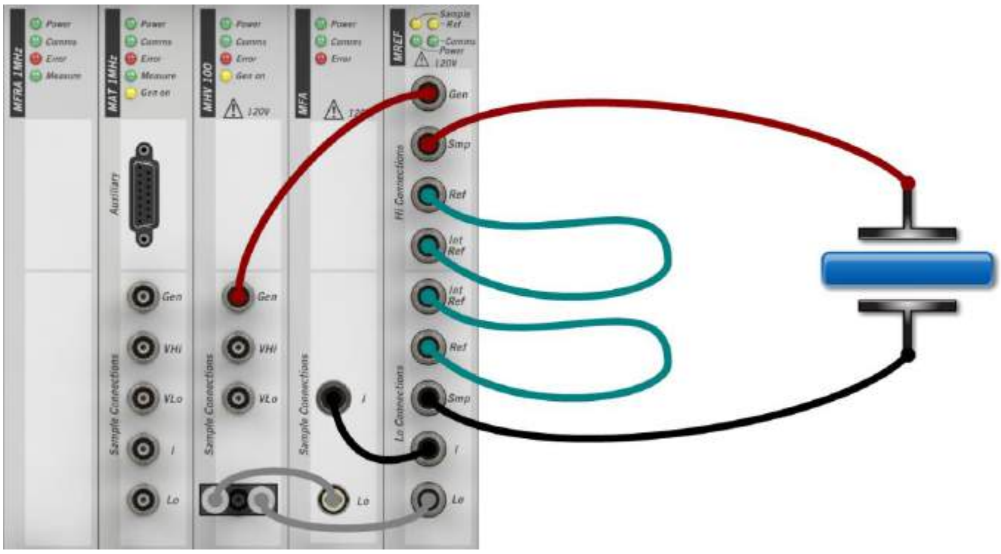


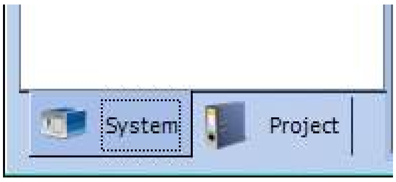
Figure 3-10 High voltage / high impedance system with internal referencing

☞ In this configuration, the Sample and Reference module has been added to High Voltage / High Impedance Materials Testing, Section 3.3.2.4.

☞ The alternative connection diagram for external referencing is available by selecting User Reference in the Sample and Ref field, in the Sample Setup, Section 5.3.3.

4. Software Reference: System

The ModuLab XM MTS user interface is divided into two main sections, System and Project, depending on the tab that has been selected at the bottom of the left-hand navigation panel.



This Chapter describes the features available under the System tab, which are:

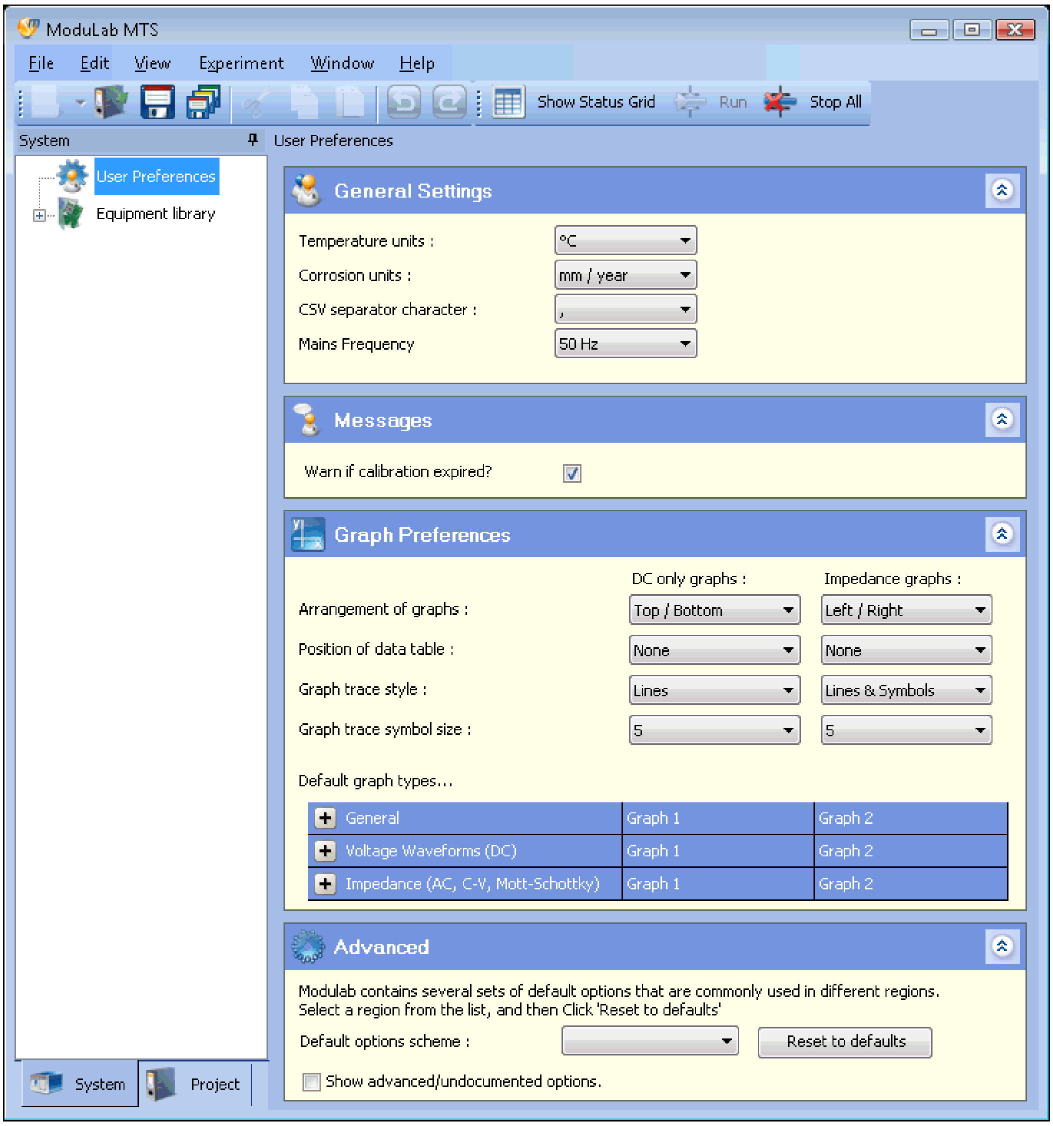
- ☞ User Preferences, Section 4.1.
- ☞ Equipment Library, Section 4.2.

Details of experiments, results and reports are available in the Software Reference for the features under the Project tab.

- ☞ Software Reference: Project, Chapter 5.

4.1 USER PREFERENCES

The User Preferences screen displays general information about the ModuLab XM system and software. This screen is available from the User Preferences item in the left-hand navigation panel, with the System tab selected. When all the sub-screens are expanded, it appears as follows:

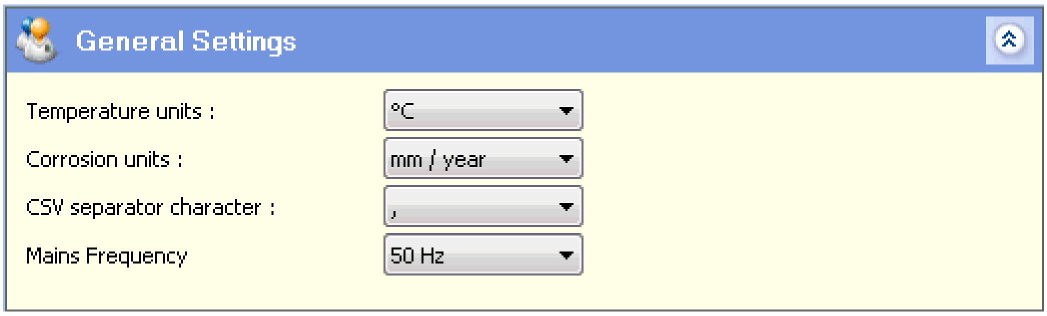


The User Preferences are unique to each user of the system. When a user logs in to Windows and runs the ModuLab XM software, their specified preferences are applied to all projects.

☞ The sub-screens are discussed in sub-sections 4.1.1 to 4.1.4.

4.1.1 General Settings

This sub-screen in the User Preferences screen defines general information for the ModuLab XM system.



The fields are as follows:

Temperature units

The units of temperature at which measurements are made. The units may be:

°C
°F
K

Corrosion units

The units in which corrosion rates are measured. The units may be:

mm/year
mil/year (mil = 1/1000 inch)

CSV separator character

The character which separates successive data fields in a CSV file. It may be:

,
;
Tab

Mains Frequency

The frequency of the mains power supply, which may be:

50 Hz
60 Hz

This is used in the Time Domain Measurement Setup, where an integration period can be specified in units of mains cycles.

☞ Time Domain Measurement Setup, Section 5.7.2.

4.1.2 Messages

This sub-screen in the User Preferences screen contains boxes which you can check to select messages to be displayed in various circumstances.

In the current version there is just one message:

Warn if calibration expired?

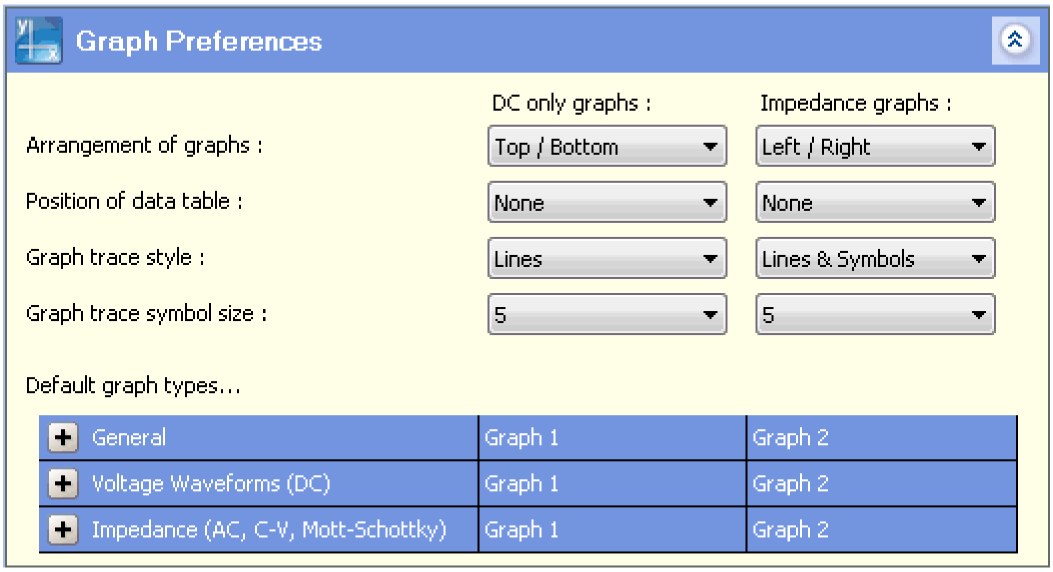
A message is displayed if the calibration of a module has passed its expiry date and needs to be returned to Solartron for recalibration.

4.1.3 Graph Preferences

This sub-screen in the User Preferences screen defines options to be applied to graphic and tabulated data, when *experiments* have been run and results are displayed. Most of the options specified here are defaults which can be changed from the Graph Setup sub-screen, when setting up a *step*, or from the Axes or Trace Setup sub-screens, when displaying data.

☞ Graph Setup, Section 5.7.6.
☞ Axes, Section 5.11.1.
☞ Trace Setup, Section 5.10.4.

When the User Preferences screen is first opened, it appears as follows:



The following fields apply generally to graphs and tables, without reference to the *step type*, but the options can be specified separately for **DC only graphs** and **Impedance graphs**.

Arrangement of graphs

When two graphs are displayed, by specifying both Graph 1 and Graph 2 in the Graph Setup or Axes sub-screens, the graphs can be displayed alongside each other from left to right, or one above the other from top to bottom. The options are:

Left/Right
Top/Bottom

Position of data table

This field defines the default position of tabulated data in relation to the graphs. The options are:

None	Do not display tabulated data.
Right	Display tabulated data to the right of the graphs.
Bottom	Display tabulated data below the graphs.

The options can be changed from the Axes sub-screen when the results are displayed.

Graph trace style

This field defines the default options for displaying data as lines and symbols on the graphs. The options are:

Lines
Symbols
Lines & Symbols

The options can be changed from the Trace Setup sub-screen when the results are displayed.

Graph trace symbol size

The default size of symbols, when used to display graphic data. The options are the odd numbers from 1 to 15. The symbol sizes can be changed from the Trace Setup sub-screen when the results are displayed.

Default Graph Types

In this group of fields, each row represents a *step* category, and you can click the rows to expand the categories and display the *step types* as follows:

Default graph types...

General	Graph 1	Graph 2
Open Circuit	V vs. Time	None
Run External Program	V vs. Time	None
Temperature Settle	V + Temp vs. Time	None
Voltage Waveforms (DC)	**Graph 1**	**Graph 2**
Constant Level	I vs. Time	None
Linear Sweep I-V Characterisation	I vs. V	None
Triangular Sweep I-V Characterisation	I vs. V	None
Sweep Pulse	I vs. V	None
Differential Pulse	I vs. V	None
Square Wave	I vs. V	None
Staircase Linear Sweep	I vs. V	None
Staircase Triangular Sweep	I vs. V	None
Pulse	I vs. V	None
Impedance (AC, C-V, Mott-Schottky)	**Graph 1**	**Graph 2**
Constant level	Bode (| Z |, Θ)	None
Linear Sweep	| Z | + Θ vs. V	None
Triangular Sweep	| Z | + Θ vs. V	None
Staircase Linear Sweep	| Z | + Θ vs. V	None
Staircase Triangular Sweep	| Z | + Θ vs. V	None

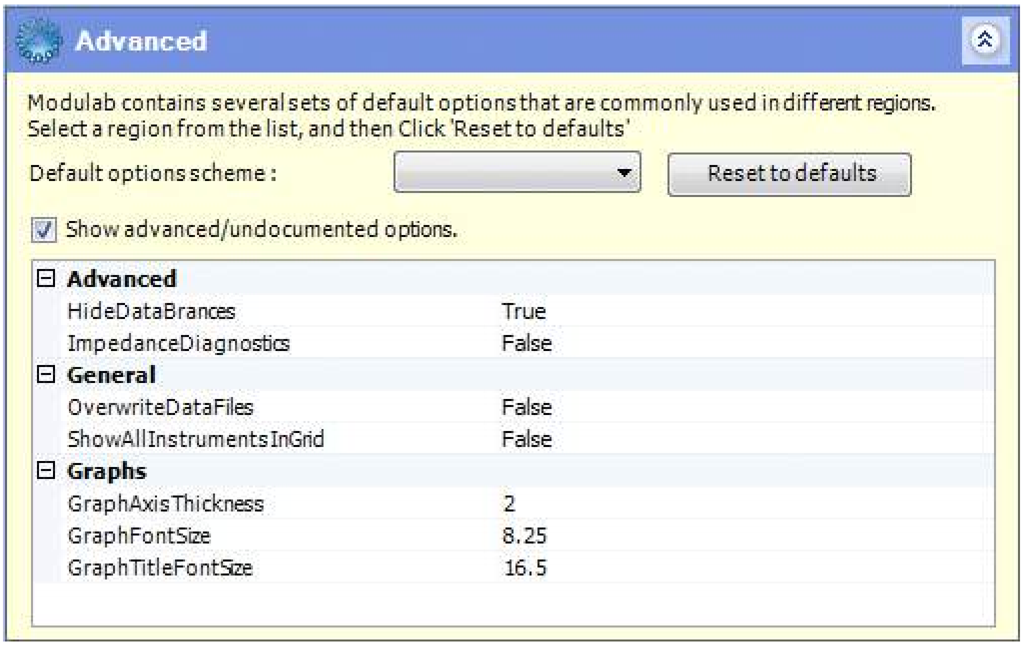
There is one row for each *step type*, containing drop-down list boxes for the default variables to be displayed on two graphs, called Graph 1 and Graph 2. The available variables for DC and impedance *steps* are listed in the Layout of Graphic Displays.

The option for Graph 2 defaults to “none” because you would normally want to specify variables that are different from Graph 1.

☞ Layout of Graphic Displays, Section 5.11.1.

4.1.4 Advanced

This sub-screen in the User Preferences screen defines advanced options for ModuLab XM.



The fields are:

Default options scheme

This specifies a collection of default options to be used in cases where they are required to be country-specific. The list box has the following entries:

UK
Europe
USA

The selected option, together with the Reset to defaults button, will apply the country-specific defaults throughout ModuLab XM. For example, in the General Settings, the Temperature units will be set to °C for the UK and °F for the USA.

☞ General Settings, Section 4.1.1.

Reset to defaults

If any optional values in the program have been changed, this button resets them to their default values.

Show advanced/undocumented options

If this box is checked, the sub-panel opens so that you can change various features of the software that are not available from the other screens. This list of features may change from time to time with new software versions.

4.2 EQUIPMENT LIBRARY

The Equipment library gives a description of the hardware that makes up the ModuLab XM MTS system, and is defined by a set of items in the left-hand navigation panel, with the System tab selected.

The Equipment library item is at the top of the hierarchy, and underneath it there are other items as follows:

- There is a chassis item for each chassis in the system.
- Underneath each chassis there are *instrument group* items, representing a core module and a number of optional modules which are specified automatically or manually as follows:
  - The high voltage module, femto ammeter and 2A booster are automatically detected by the system.
  - The frequency response analyzer has to be specified by the user in the Instrument Group Setup.

    ☞ Instrument Group Setup, Section 4.2.3.
  - A temperature controller can be manually added to the *instrument group*.

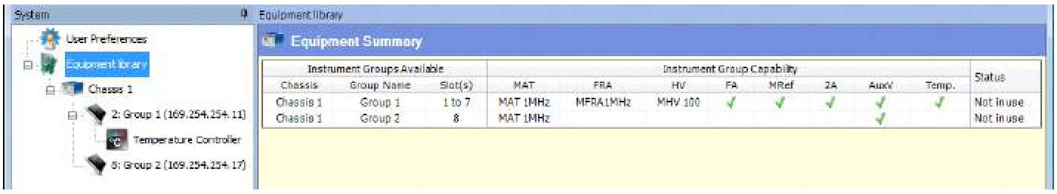
    ☞ Temperature Controller, Section 4.2.4.

It is possible to set up virtual equipment and run simple *experiments* for test purposes, without actually having any equipment.

☞ Virtual Equipment, Section 4.2.5.

4.2.1 Equipment Summary

The Equipment Summary is available from the Equipment library item, at the top of the equipment hierarchy as follows:



The summary consists of a tabulated list of equipment, with one row for each *instrument group*, and with columns representing the features of the group. The rows can be re-arranged into reverse order by clicking the headers.

NOTE: The tabulated list only appears on systems where equipment has been installed, otherwise there will be a Search button to identify the system hardware.

☞ Installation Guide

In a system where equipment has been installed, the columns in the tabulated list are as follows:

Instrument Groups Available

This set of columns identifies the *instrument groups* and their location in a *chassis*.

The columns are:

Chassis

The *chassis* to which the *instrument group* belongs. The name is specified in the General Settings for the chassis, otherwise it defaults to “Chassis”.

☞ Chassis, Section 4.2.2.

Group Name

The name of the *instrument group*, defined in the Instrument Group Setup. The name defaults to “Instrument Group”, but you need to give each group a unique name, for example Group 1, Group 2, etc.

☞ Instrument Group Setup, Section 4.2.3.

Slot(s)

The slots in which the core module and optional modules, which make up the group, are fitted in the chassis. The system automatically detects the slot numbers.

Instrument Group Capability

This set of columns gives the specification of the core module and optional modules. The columns are:

MAT

The model of the core module, detected automatically by the system. There is currently only one model:

MAT 1MHz

FRA

The FRA model. The user has to specify that an FRA exists, in association with the core module, and then the system automatically detects the model. There is currently only one model:

MFRA 1MHz

☞ The existence of the FRA is specified in the Instrument Group Setup, Section 4.2.3.

HV

The model of the high voltage module, if fitted. This is detected automatically by the system and there is currently only one model:

MHV 100

FA

This field is ticked if a femto ammeter is fitted. This module is automatically detected by the system.

MRef

This field is ticked if a sample and reference module is fitted. This module is automatically detected by the system.

2A

This field is ticked if a 2A booster is fitted. This module is automatically detected by the system.

AuxV

This field is ticked if auxiliary voltage channels are available to the group. The auxiliary channels are automatically detected by the system.

Auxiliary channels are fitted as standard to the ModuLab XM MTS system but may be optional in other versions of ModuLab XM.

Temp.

This field is ticked if a temperature controller is included in the group.

Status

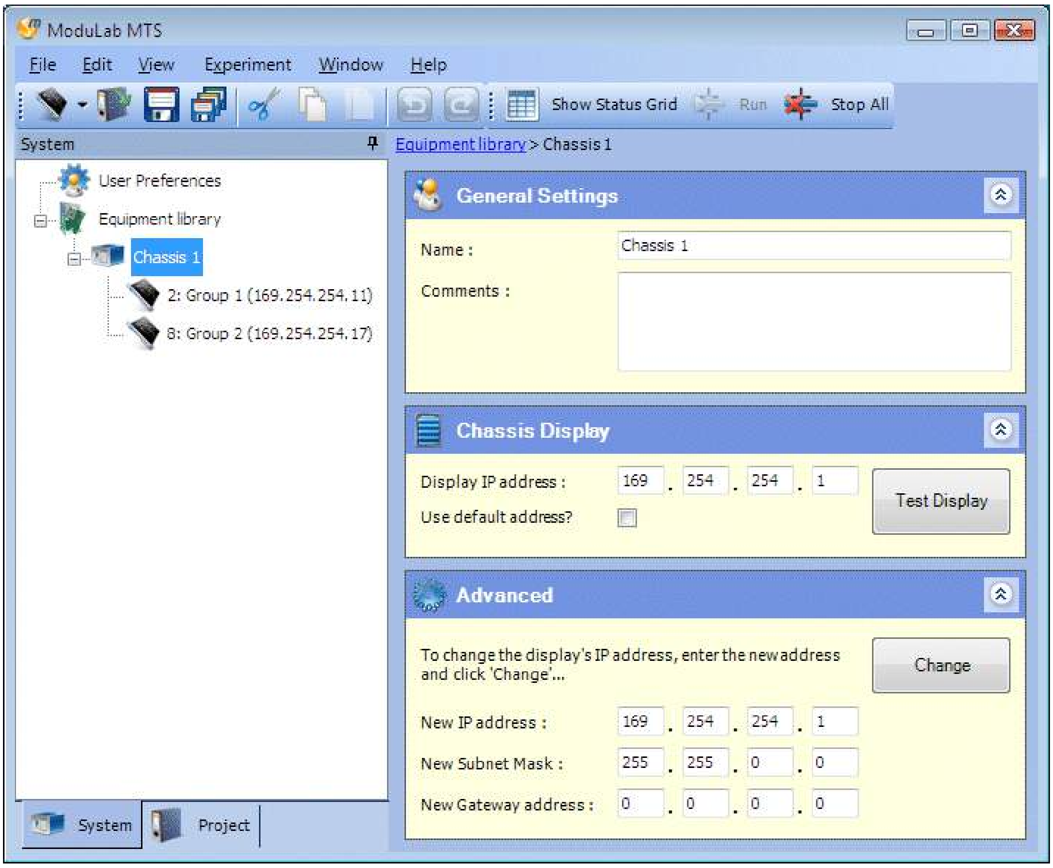
The current status of the *instrument group*, same as in the Module Information. The status values are:

Measuring	The group is currently taking a measurement.
In use	The group is currently being used by this copy of the ModuLab XM software and cannot be used by anyone else.
Experiment Limit	The group is currently being used for an *experiment*, but the *experiment* has paused because a measurement has reached a limiting value.
Not in use	The group is not being used.
Error	The group has been running an *experiment* which has paused or stopped because of an error. This can occur for a number of different reasons, and more specific information is given in the Status Grid. ☞ Status Grid, Section 2.6.

☞ Module Information, Section 2.6.3.

4.2.2 Chassis

The Chassis item is located under the Equipment library item. There will be at least one of them as part of the installation, but you can add new ones if required. The display associated with the Chassis is as follows:



The right-hand window is divided into sub-screens, each with their respective fields as follows:

General Settings

Name

A name for the chassis, in case there is more than one of them. The default name is Chassis, but if there is more than one of them, they will each need to be given unique names.

Comments

A free-format text field in which you can type a description of the chassis.

Chassis Display

Display IP address

The IP address of the chassis display panel. The correct address, corresponding to the chassis display, has to be entered to enable the PC to communicate with the display. You can enter a four-part number, then click the Test Display button to implement it within the ModuLab XM software and perform a communication test.

Normally the default address should be used, but an alternative address will be required if there is already a device on the network that uses the default address, for example the display panel in another chassis.

☞ Installation Guide for details of how to set up IP addresses on the system.

Use default address?

If this box is checked, the default address 169.254.254.1 appears in the Display IP address field, and the field becomes greyed out.

Test Display

This button implements the specified address within the ModuLab XM software, and if communication is successful it displays a test message on the chassis display. A message will also appear on the PC, to the right of the button.

Advanced

This sub-screen can be used to change the IP address of the chassis front panel display, and at the same time implement the new address within the ModuLab XM software and perform a communication test.

CAUTION: This feature changes the address within the ModuLab XM hardware, and you will need to make a note of the new address in case it is needed within the Chassis Display sub-screen. If the new address is lost, you will no longer be able to communicate with the display and will have to return the chassis to Solartron for testing.

The fields are:

New IP address

The new IP address to be used for the chassis display.

New Subnet Mask

The subnet mask associated with the new IP address for the chassis display.

New Gateway address

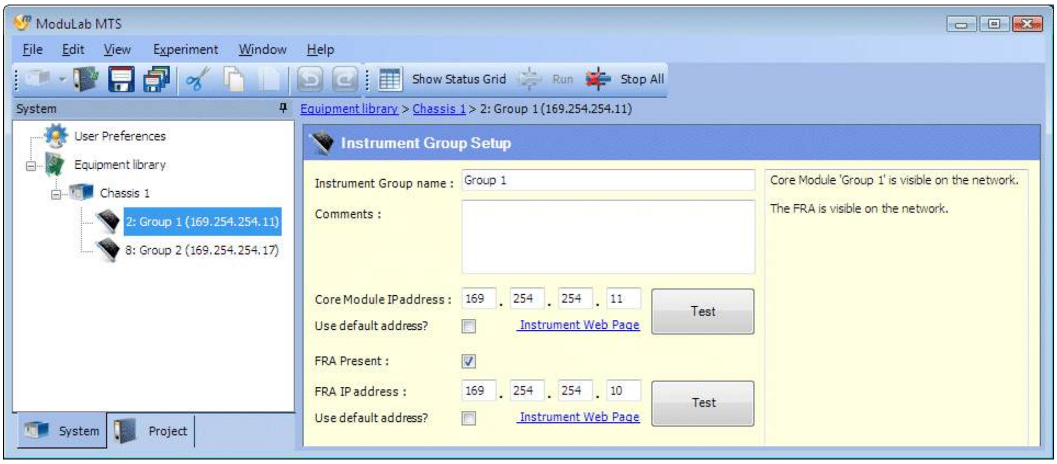
The gateway address associated with the new IP address for the chassis display.

Change

This button implements the address within the ModuLab XM hardware and software, according to the values in the three fields (New IP address, New Subnet Mask and New Gateway address). If communication is successful it displays a test message on the chassis display. A message will also appear on the PC, to the right of the button. The new address will appear in the Display IP address field in the Chassis Display sub-screen.

4.2.3 Instrument Group Setup

Any number of *instrument groups* can be fitted to a *chassis*, according to the number of available slots and the optional modules within each group. The *instrument groups* appear in the left-hand navigation panel under the *chassis*, and each of them displays an Instrument Group Setup screen as follows:



The fields are as follows:

Instrument Group name

A name for the *instrument group*. This defaults to “Instrument Group”, but you should specify a unique name for each group, for example Group 1, Group 2, etc..

Comments

A free-format text field in which you can type a description of the core module.

Core Module IP address

The IP address of the core module. The correct address, corresponding to the core module, has to be entered to enable the PC to communicate with it. You can enter a four-part number, then click the Test button to implement it within the ModuLab XM software and perform a communication test. Normally the default address should be used, but an alternative address will be required if there is already a device on the network that uses the default address.

☞ Installation Guide for details of how to set up IP addresses on the system.

Use default address?

If this box is checked, the default address 169.254.254.*n* appears in the Core Module IP address field, where *n* is the slot number plus 10, and the field becomes greyed out.

Test

This button implements the specified Core Module IP address within the ModuLab XM software, and tests the core module and optional modules, but not the FRA. If communication is successful it displays a list of modules on the chassis front panel, updating it with the latest changes. A message will also appear on the PC, in the display panel at the right of the sub-screen.

Instrument Web Page

This hyperlink communicates with the core module and displays information about it as a web page. This includes the IP address of the card, in case it needs to be changed.

CAUTION: If you change the address of the core module hardware, you will need to make a note of the new address in case it is needed within the ModuLab XM software. The address remains on the card when it is moved from one chassis to another, and if the address is lost, you will no longer be able to communicate with the core module and will have to return it to Solartron for testing.

FRA Present

If an FRA is fitted, this box needs to be checked to indicate its existence, then the system can identify the model and access its features, and the model will appear in the Equipment Summary. There is currently only one model:

MFRA 1MHz

☞ Equipment Summary, Section 4.2.1.

FRA IP address

The IP address of the FRA. The correct address, corresponding to the FRA, has to be entered to enable the PC to communicate with it. You can enter a four-part number, then click the Test button to implement it within the ModuLab XM software and perform a communication test. Normally the default address should be used, but an alternative address will be required if there is already a device on the network that uses the default address.

☞ Installation Guide for details of how to set up IP addresses on the system.

Use default address?

If this box is checked, the default address 169.254.254.*n* appears in the FRA IP address field, where *n* is the slot number plus 9, and the field becomes greyed out.

Test

This button implements the specified FRA IP address within the ModuLab XM software, and it also tests the core module and optional modules, as if the Test button associated with the core module had been pressed. If communication is successful it displays a list of modules on the chassis front panel, updating it with the latest changes. A message will also appear on the PC, to the right of the button.

Instrument Web Page

This hyperlink communicates with the FRA and displays information about it as a web page. This includes the IP address of the card, in case it needs to be changed.

CAUTION: If you change the address of the FRA hardware, you will need to make a note of the new address in case it is needed within the ModuLab XM software. The address remains on the card when it is moved from one chassis to another, and if the address is lost, you will no longer be able to communicate with the FRA and will have to return it to Solartron for testing.

4.2.4 Temperature Controller

A temperature controller can be included in an *instrument group*, for the purpose of conducting *experiments* where the sample has to be maintained at a specified temperature during each *step*.

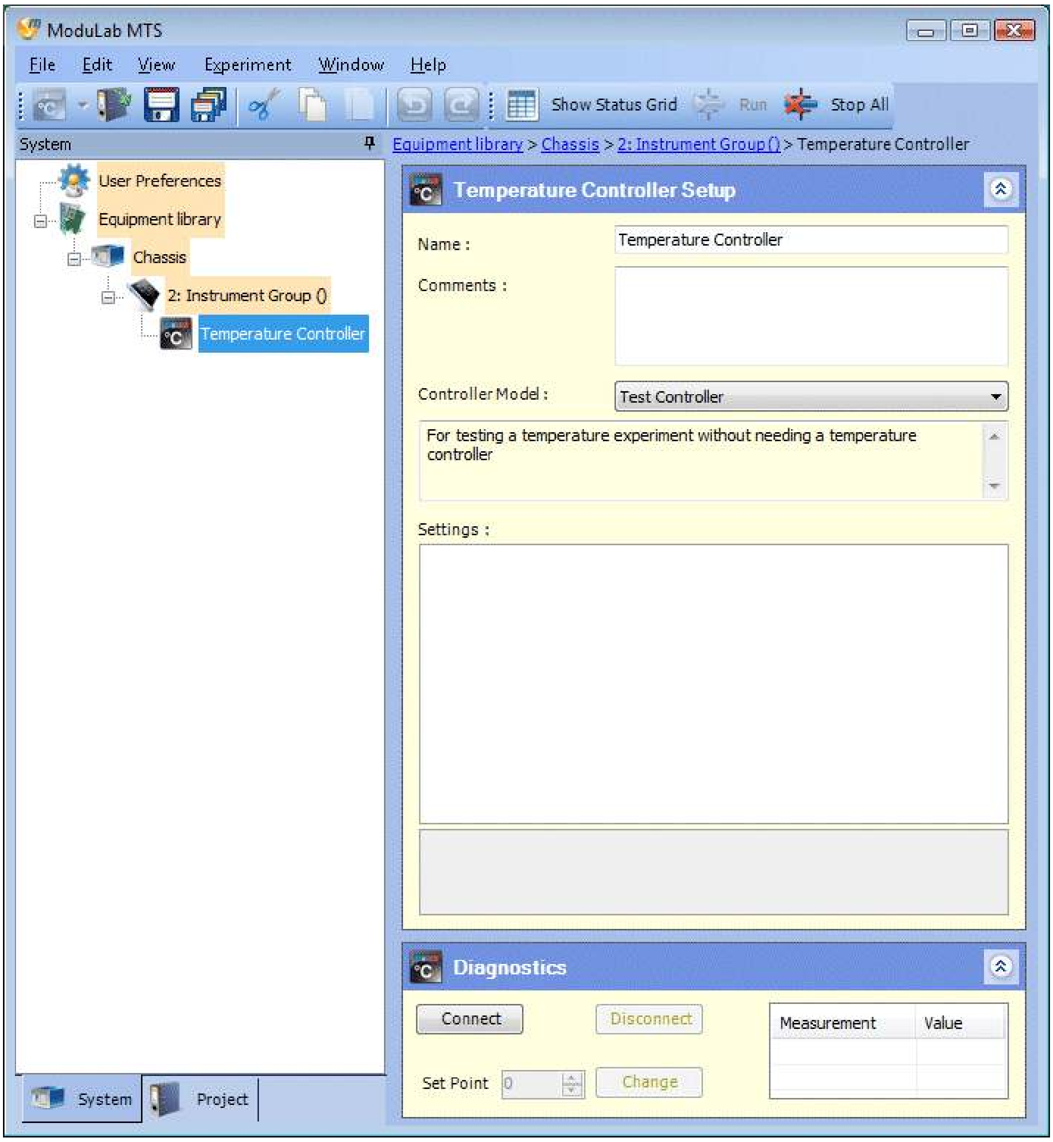
To add a temperature controller to an *instrument group*:

1. Click on the System tab, at the bottom of the navigation panel.
2. Right-click on the Instrument Group item, then click Add New and Temperature Controller. The Temperature Controller item will appear under the *instrument group*.

   NOTE: The temperature controller has to be added manually to the system because it is not part of the chassis and is not detected automatically by the Search button in the Equipment Summary, during the ModuLab XM installation.

   ☞ Installation Guide, for details of how to search for equipment.

When a temperature controller is selected in the left-hand navigation panel, the Temperature Controller screen appears as follows:



The Temperature Controller Setup sub-screen has the following fields:

Name

The name of the temperature controller

Comments

A comment field, so you can specify the purpose of the temperature controller, and any other relevant information.

Controller Model

The model of the temperature controller. The options are:

None
Eurotherm 2000 Series
Lakeshore
Manual Control
Test Controller

The text field underneath this field gives details of the selected model.

Settings

This field contains two sub-panels:

- The upper panel contains a set of fields, appropriate for the selected model, so you can specify the settings for the model.
- The lower panel contains a description of the field selected in the upper panel.

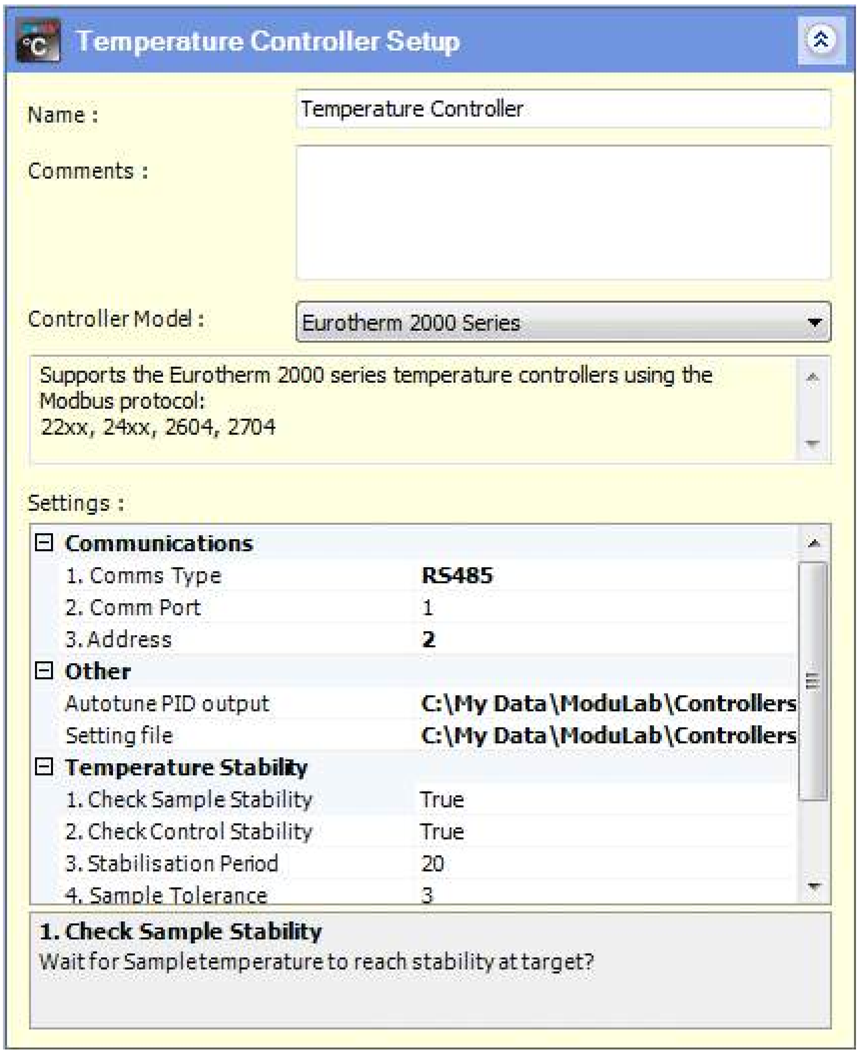
☞ The settings for the available models are described in Sections 4.2.4.1 - 4.2.4.2.

The Diagnostics sub-screen enables you to test the controller and take measurements, independently of any *experiments*.

☞ Diagnostics, Section 4.2.4.6.

4.2.4.1 Eurotherm 2000 Series Temperature Controller

When the Eurotherm 2000 Series temperature controller is selected as the Controller Model, the Temperature Controller Setup screen displays the appropriate fields in the Settings panel as follows:



The fields in the Settings panel are as follows:

Communications

This group of fields specifies the communication between the PC and the temperature controller. The fields are:

Comms Type

The communications type. The list box contains the following options:

RS232
RS485

Comm Port

The COM port number to which the controller is connected. You can type a number from 1 to 256.

Address

The device address to be used when the communications type is RS485. You can type a number from 1 to 255.

Other

This group has the following fields:

Autotune PID output

When an experiment is run with Autotune enabled, the system calculates the proportional, integral and derivative control parameters for optimum performance and writes them to a file. The default pathname is:

C:\My Data\ModuLab\Controllers\AutoTunePID.txt


When you click on the field, this button appears at the right of the pathname so you can display a filing system dialogue box and open the file in Windows Notepad. The file will only exist if a temperature control *experiment* has already been run.

Setting file

The pathname of the file containing the Eurotherm controller settings. The default pathname is:

C:\My Data\ModuLab\Controllers\Eurothrm.set


When you click on the field, this button appears at the right of the pathname so you can display a filing system dialogue box and select a different settings file. You can also right-click on any filename in the dialogue box, then click Edit to open the file for editing in Windows Notepad.

Some of the variables in the settings file correspond to the Temperature Stability group. Normally the system will use the values specified in the group, but if you change them within the file, the system will use the values from the file, not the group. For all other settings, the system always uses the values from the file. The variables in the file appear under the following headings:

Serial Comms Setup

You can change the baud rate if you have a COM port that does not use the default value of 9600.

Heater / Sample

The model 2700 controller supports the use of both heater control (the control thermocouple in the space between the heating or cooling element and the sample), and sample control (the thermocouple directly on the sample). If sample control is not required you can disable it and use heater only control.

Temperature Stabilisation / Stability Parameters

Under these two headings there are some comments about the stability parameters, followed by the parameters themselves. You can edit the parameters, but it should not be necessary because you can specify the values in the appropriate fields in the Temperature Stability group.

PID Control

Autotune should normally be used initially to calculate the optimum PID parameters for a temperature control system, and then the parameters can be copied from AutoTunePID.txt to Eurotherm.set for future use with Autotune disabled.

Alternatively you can edit Eurotherm.set with your own specific values if required.

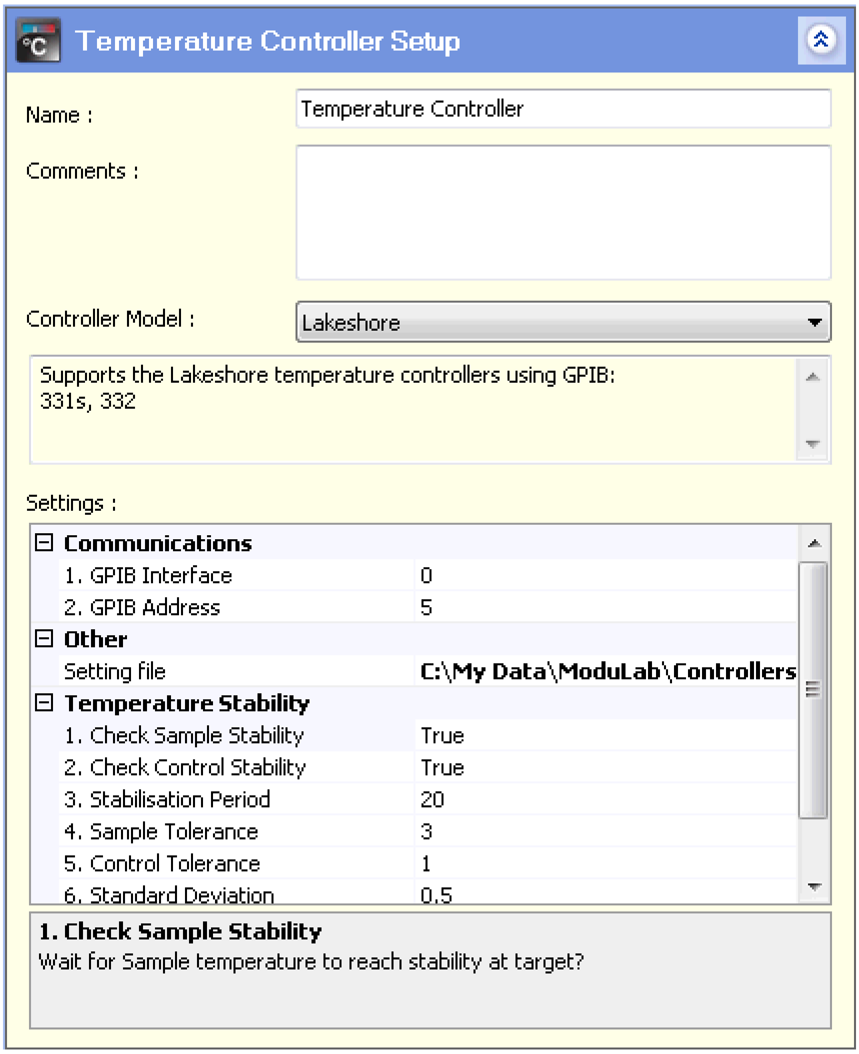
Temperature Stability

This group of fields is common to all temperature controllers, and specifies the conditions when temperature is considered to be stable at a value close to the set point, for the purpose of temperature control *experiments*.

☞ Temperature Stability, Section 4.2.4.3.

4.2.4.2 Lakeshore Temperature Controller

When the Lakeshore temperature controller is selected as the Controller Model, the Temperature Controller Setup screen displays the appropriate fields in the Settings panel as follows:



The fields in the Settings panel are as follows:

Communications

This group of fields specifies the communication between the PC and the temperature controller. The fields are:

GPIB Interface

The address of the GPIB interface bus, to which multiple devices can be connected.

GPIB Address

The address of the temperature controller on the GPIB bus.

Other

This group has just one field:

Setting file

The pathname of the file containing the Lakeshore controller settings. The default pathname is:

C:\My Data\ModuLab\Controllers\Lakeshore332.set

When you click on the field, this button appears at the right of the pathname so you can display a filing system dialogue box and select a different settings file. You can also right-click on any filename in the dialogue box, then click Edit to open the file for editing in Windows Notepad.

Some of the variables in the settings file correspond to the Temperature Stability group. Normally the system will use the values specified in the group, but if you change them within the file, the system will use the values from the file, not the group. For all other settings, the system always uses the values from the file. The variables in the file appear under the following headings:

Temperature Stabilisation / Stability Parameters

Under these two headings there are some comments about the stability parameters, followed by the parameters themselves. You can edit the parameters, but it should not be necessary because you can specify the values in the appropriate fields in the Temperature Stability group.

Controller Initialisation

The variables underneath this heading apply to the initialisation procedures for the controller, and are described in the Lakeshore documentation.

Temperature Offset

The Lakeshore controller provides temperature control from the heater, which is a small distance away from the sample. This leaves the sample at a temperature which is different from the set point, and a list of offsets has to be specified to bring the sample to the correct temperature. Each entry in the list has the following format:

%TemperatureOffset=T_1,T_2

where T_1 is the required sample temperature and T_2 is the offset required to achieve it, both in K. For example:

%TemperatureOffset=110,0.75

The maximum temperature offset is 50K.

PID Configure

The Lakeshore controller does not use auto-tuning so the appropriate PID values have to be specified, as described in the Lakeshore documentation.

Enable Heater

The heater or cryostat is set to operate normally up to its maximum range.

Temperature Stability

☞ This group of fields is common to all controllers and is described in the next Section.

4.2.4.3 Temperature Stability

The Temperature Stability fields are common to all controllers, with some minor differences, and they appear in the Settings panel in the Temperature Controller Setup as follows:

⊟ Temperature Stability	
1. Check Sample Stability	True
2. Check Control Stability	True
3. Stabilisation Period	20
4. Sample Tolerance	3
5. Control Tolerance	1
6. Standard Deviation	0.5
7. Stabilisation Timeout	30

This group of fields applies stability criteria to *experiments* under temperature control. A temperature *loop* begins with a temperature settling *step* which continues until the measured temperature fulfils the stability criteria, then it moves to the next *step* in the *loop*.

☞ Temperature Loop, Section 5.9.3.

There are two temperatures that may be measured:

- The control temperature is the temperature of the heater or cooler, measured by a thermocouple in the space between the sample and the heating or cooling element.
- The sample temperature is the temperature measured by a thermocouple placed directly on the sample. This feature is only available on the following controller models:

  Eurotherm 2604
  Eurotherm 2704
  Lakeshore 331s
  Lakeshore 332

Two different tests are applied to a collection of the latest measurements, and the set point is considered to have been reached when both of these are fulfilled:

- Tolerance Test. The measurements are all within a specified tolerance value of the set point.
- Standard Deviation Test. The standard deviation of the measurements is below a specified value.

The fields in this group are as follows:

Check Sample Stability / Check Control Stability

These two fields specify whether or not to wait for the sample or control temperature to reach stability, according to the specified tolerances and standard deviation. For each field, the options are:

True
False

If both fields are set to True, the set point has been reached when both the sample and control temperatures have become stable.

At least one field should be set to True, to achieve meaningful temperature settling. If both fields are set to False, the system immediately considers the set point to have been reached.

Stabilisation Period

The period of time during which the latest temperature measurements are collected, at the rate of one measurement / second, for the purpose of testing for tolerance and standard deviation. This field applies equally to the collection of sample and control temperatures, and should normally be set to about 20 seconds, but may have a maximum value of 300 seconds.

Sample Tolerance / Control Tolerance

These two fields specify the tolerance values to be applied to measurements of the sample and control temperatures, so that the Tolerance Test is fulfilled when all the measurements taken during the Stabilisation Period are within this value of the set point. These fields should normally be set to about 2K.

Standard Deviation

The system calculates a moving standard deviation of the latest collection of temperature measurements, and when it falls below the value specified in this field, it is considered to have fulfilled the Standard Deviation Test. This field should normally be set to about 0.5K or less.

Standard deviations are calculated separately for sample and control temperatures, so that two tests can be performed, both using the value in this field.

The time period for collection of measurements is specified in the Stabilisation Period field.

Stabilisation Timeout

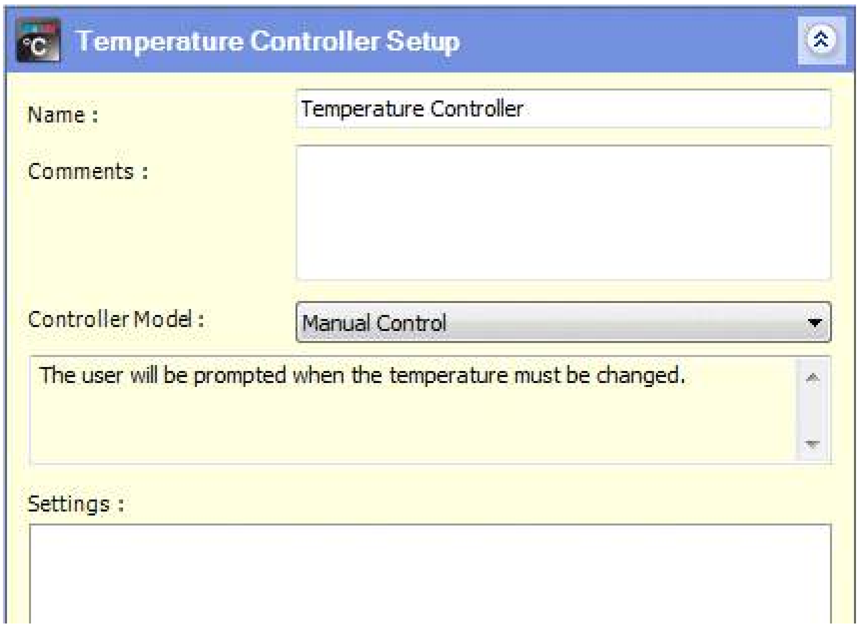
Normally it will take some time for the sample temperature to become stable after the control temperature has become stable (if the same tolerances are applied in each case).

This field specifies the maximum time in minutes that the system will wait, after the control temperature has become stable, and when this period expires the sample temperature is also considered to be stable.

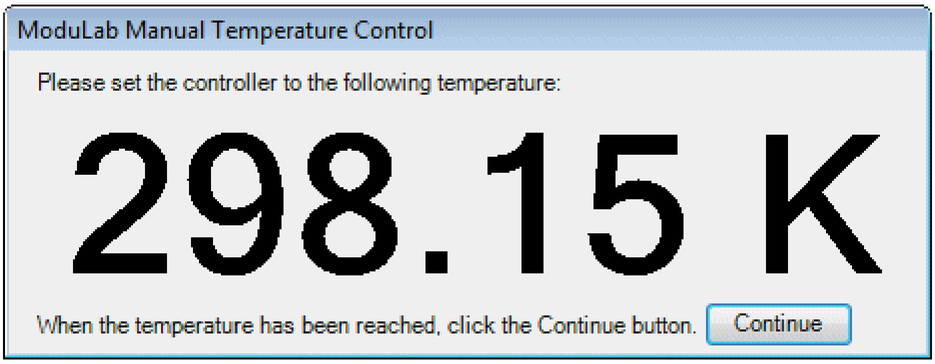
This field is available for the Lakeshore controllers, but not the Eurotherm 2000 Series controllers.

4.2.4.4 Manual Control

When Manual Control is selected as the Controller Model, the Temperature Controller Setup screen displays a blank Settings panel as follows:



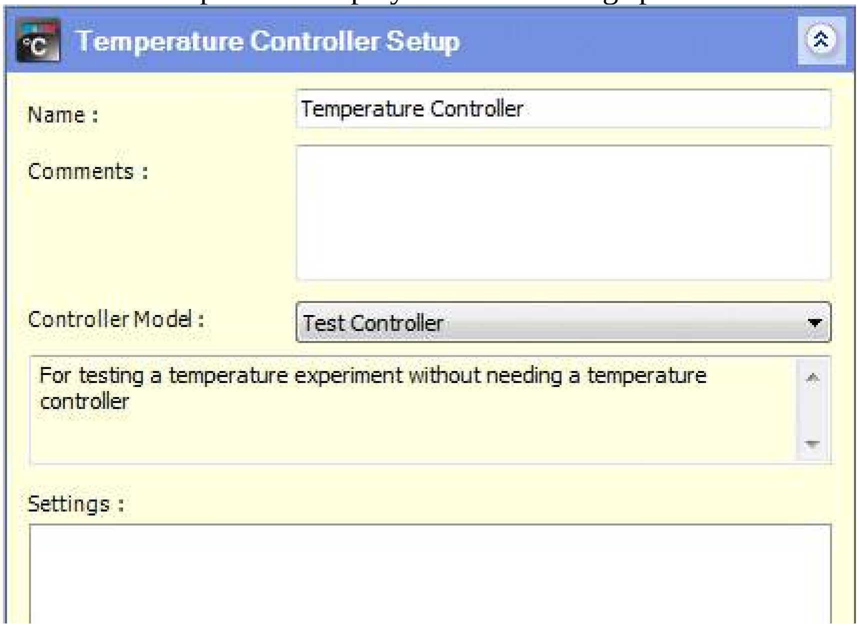
Manual Control is used for *experiments* where an unsupported temperature controller is being used, that cannot be connected to the ModuLab XM system. During the *experiment*, the user is prompted to manually set the controller to a specific temperature, then click Continue when the temperature is reached. A typical prompt is as follows:



This feature enables *experiments* to be run with any temperature controller, but the user must be present to respond to each successive prompt.

4.2.4.5 Test Controller

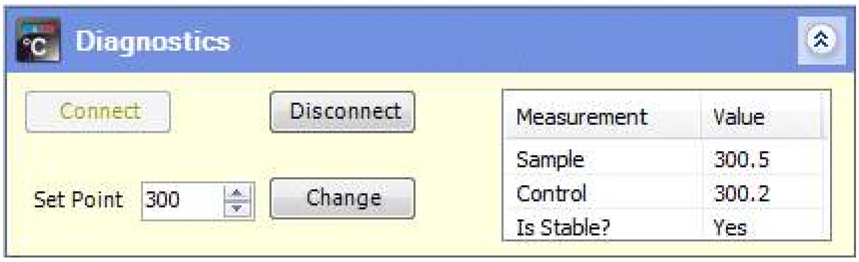
When Test Controller is selected as the Controller Model, the Temperature Controller Setup screen displays a blank Settings panel as follows:



This enables you to run temperature control *experiments*, for test purposes, when a temperature controller is not available. The Test Controller has no settings.

4.2.4.6 Temperature Controller Diagnostics

The Diagnostics sub-screen, in the Temperature Controller screen, enables you to test the controller and take measurements, independently of any experiments. The sub-screen is as follows:



The fields are as follows:

Connect

This button establishes communication with the controller, so that it starts taking measurements. If communication fails, a dialogue box will appear giving the reason.

Disconnect

This button discontinues communication with the controller so that it stops taking measurements.

Set Point / Change

You can specify a value of the set point, then press the button and the measurements taken by the controller will gradually progress towards the new set point.

This pair of fields is available only when the PC is communicating with the controller, otherwise it is greyed out.

Measurement / Value

This tabulated list gives the variables being measured, such as Sample or Control, and the measured value.

4.2.5 Virtual Equipment

It is possible to add virtual *chasses* and *instruments* to the equipment library and set up simple *experiments*, then run them and get results for test purposes, without actually having any equipment.

A virtual *chassis* can be added, containing an *instrument group* with the following modules:

MAT 1MHz
MHV 100
MFA
MBST 2A
MREF

A temperature controller can also be added, although it is not part of the *chassis*.

The following features can be added to an *experiment* Setup that uses a virtual *instrument group*:

Open Circuit *step*
Constant Level *step*
Standard *loop*
Temperature *loop*, automatically containing a Temperature Settling *step*

In the Step Setup, the following fields can be given values for use with the *experiment*.

- Duration and Level, in the Scan Setup sub-screen.
- Measurement Rate, in the Time Domain Measurement Setup sub-screen.

All other fields will use their default values and any changes will be ignored.

Impedance measurements cannot be made using virtual *equipment*. If an FRA has been included in an *instrument group*, it will not be possible to run *experiments*.

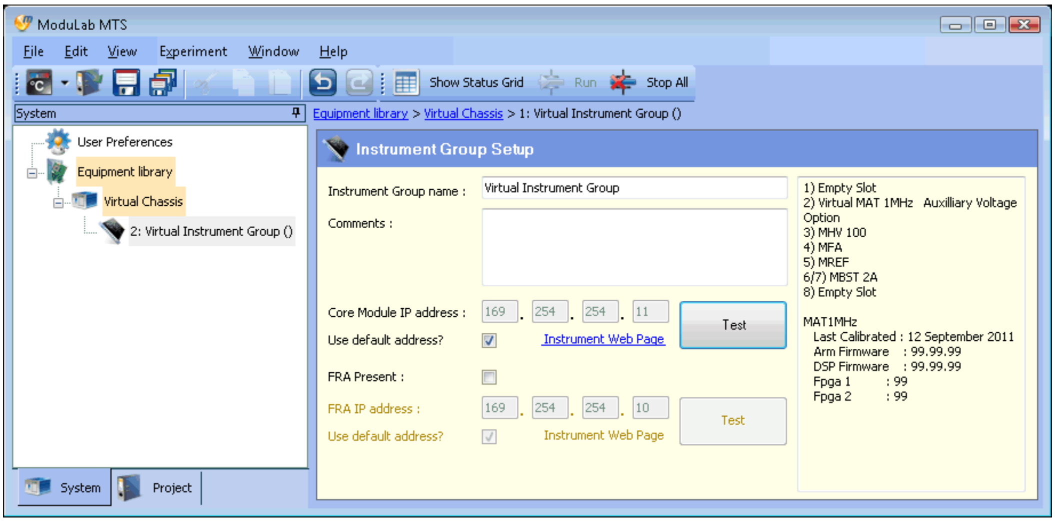
Here is an example of how to add virtual *equipment*, and set up and run an *experiment* to test a temperature controller:

1. Click on the System tab at the bottom of the navigation panel, then right-click on the Equipment Library. Click Add New, then Virtual Chassis. A new Virtual Chassis item will appear.
2. Right-click on the Virtual Chassis, select Add New and select Virtual Instrument. A new Virtual Instrument Group item will appear.

3. Click on the Virtual Instrument Group to display the Instrument Group Setup sub-screen, then click on the Test button for the core module. The group will be populated with the following modules in slots 2 to 7:

Slot 2	MAT 1MHz with AUX channels
Slot 3	MHV 100
Slot 4	MFA
Slot 5	MREF
Slots 6 and 7	MBST 2A

The screen will be as follows:

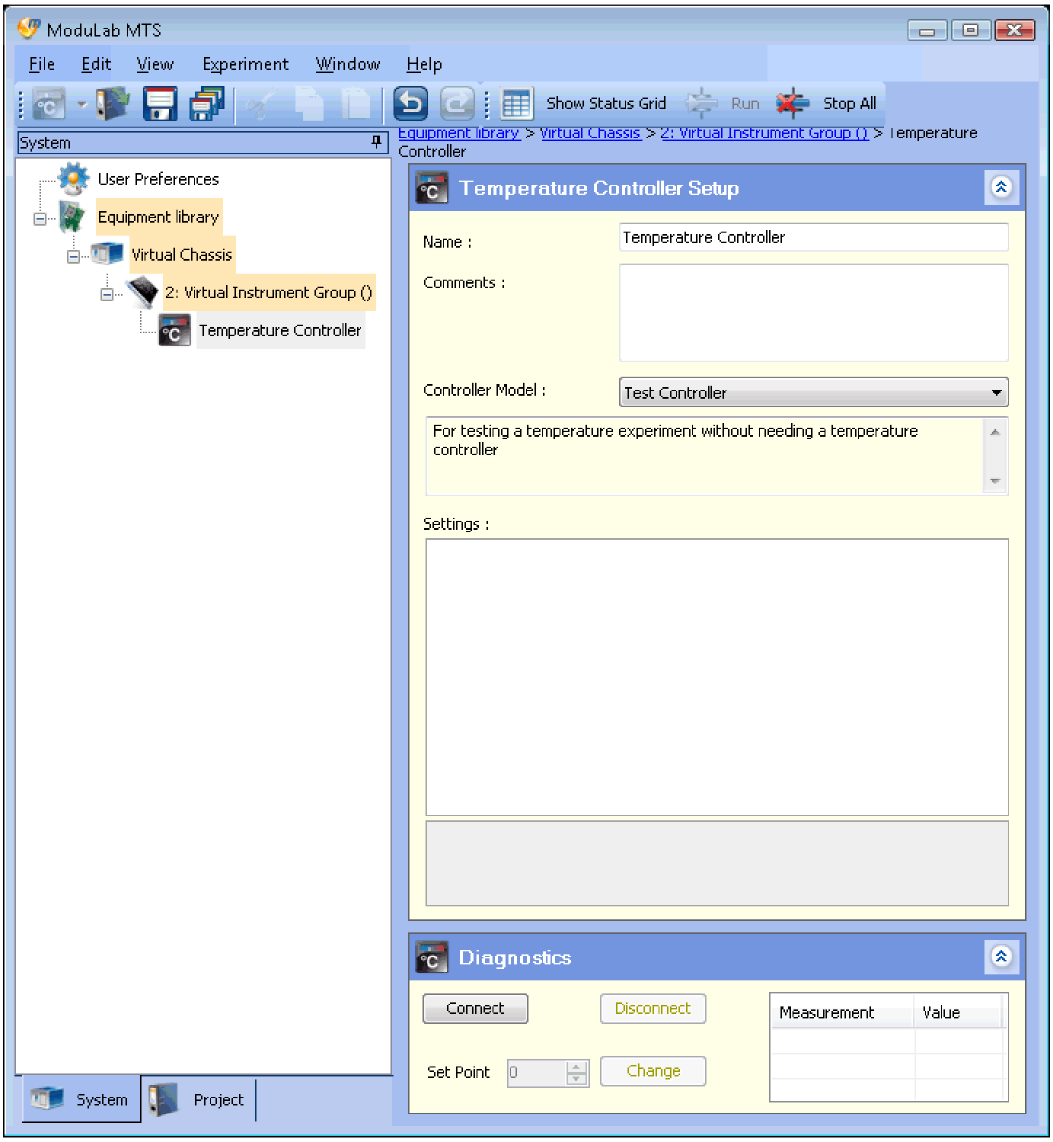


NOTE: Do not add an FRA because it is not supported in virtual equipment and will prevent *experiments* from running.

4. Right-click on the Virtual Instrument Group, then click Add New and Temperature Controller. The Temperature Controller item will appear.

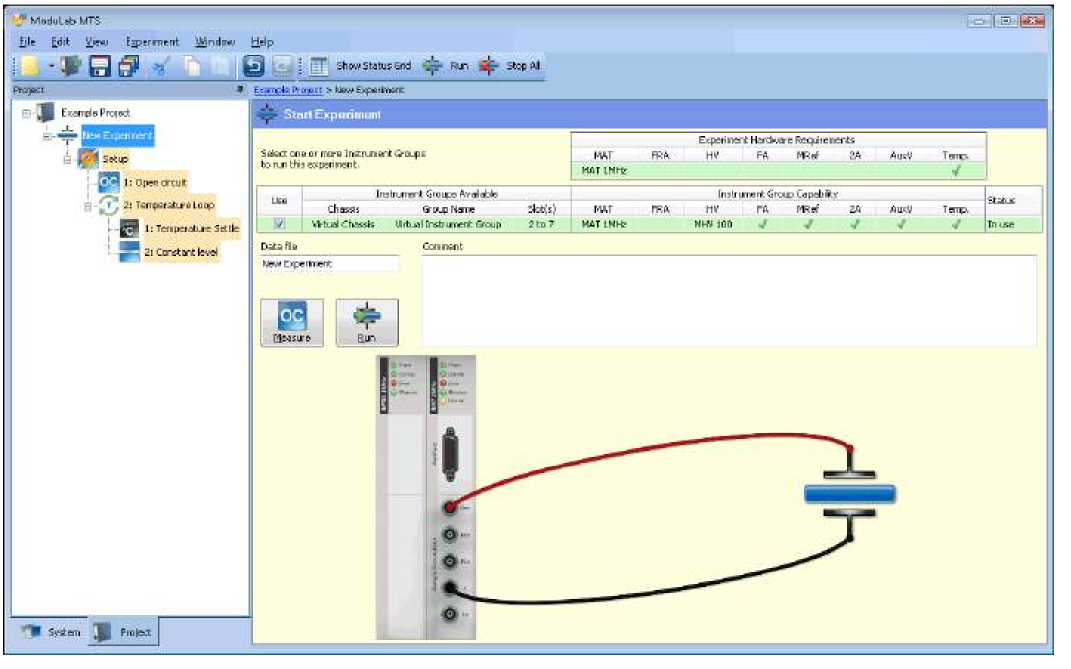
NOTE: A temperature controller always has to be added manually, because it is not part of the *chassis* and is not detected by the Test button.

5. Click on the Temperature Controller item to display the Temperature Controller Setup sub-screen, and select a controller model. You can select any model, but for the purpose of this example you can select the Test Controller because it has no settings, and nothing needs to be specified in the Settings panel. The screen will be as follows:

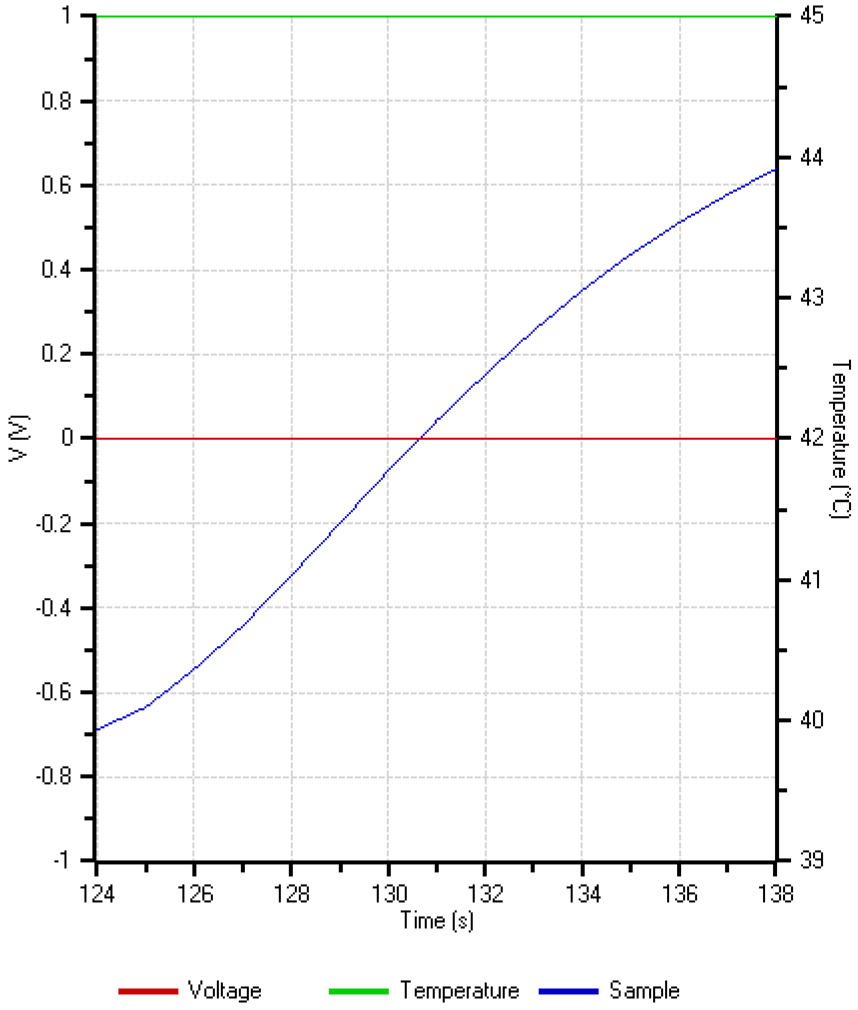


6. Click the Project tab at the bottom of the navigation panel.
7. Right-click on the Project item at the top of the navigation structure, then click on Add New, then Experiment. An *experiment* item will appear with a Setup item and an undefined *step* item in the structure underneath.
8. Click on the Setup item to display the Hardware Requirements sub-screen, then select the Virtual Instrument Group as the Instrument Group to Use.
9. Click on the undefined *step* item and define it as an Open Circuit *step*.
10. Right-click on the *experiment* Setup item, then click on Add New, then Loop, then click on Scan Temperature to define it as a Temperature *loop*.

11. Specify the fields in the Temperature Loop sub-screen as required, or leave them at their defaults.
12. The Temperature Loop will contain a Temperature Settle *step* followed by an undefined *step*. Click on the Temperature Settle *step* and edit the fields as required, or leave them at their defaults.
13. Click on the undefined *step* and define it as Constant Level.
14. Click on the Experiment item to display the Start Experiment screen and make sure the Virtual Instrument Group is selected in the Use field, so that the screen is as follows:

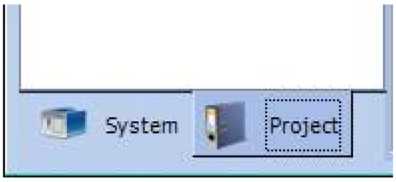


15. Click the Run button. The *experiment* will run and display the results of the Open Circuit *step*, then it will start the temperature *loop* and perform the appropriate number of cycles around the Temperature Settle *step* and Constant Level *step*. A graphic display of results will appear as follows:



5. Software Reference: Project

The ModuLab XM user interface is divided into two main sections, System and Project, depending on the tab that has been selected at the bottom of the left-hand navigation panel.



This Chapter describes the features available under the Project tab, including *projects*, *experiments*, *data*, *graphs* and *reports*.

Details of user preferences and equipment are available in the Software Reference for the features under the System tab.

☞ Software Reference: System, Chapter 4.

5.1 PROJECTS

A *project* defines all the features required to perform *experiments*, including the collection of results and their presentation in the form of tabulated lists and graphs, and the preparation of *reports*. The *project* definition is contained in the structure of items in the navigation panel when the Project tab is selected.

☞ Structure of items in a *project*, Section 2.1.2.

☞ Items and sub-items available for addition to a *project*, using Add New from the File menu, Section 2.4.1.

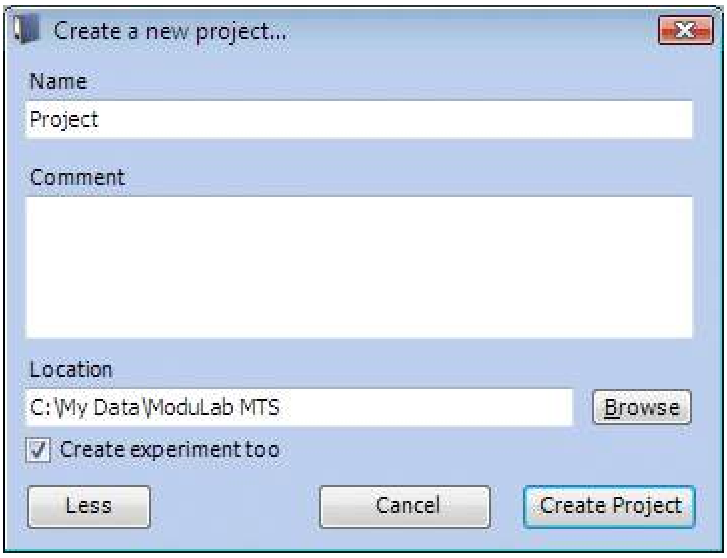
The *project* does not contain any information about the system hardware, but it has to reference a correct definition of the hardware from the Equipment library, to enable the *experiments* to work. For example, an *experiment* can only reference the core module and other modules that are installed in the system and are present in the Equipment library.

☞ System, Section 2.1.1

☞ Equipment Library, Section 4.2.

5.1.1 Create New Project

A new *project* can be created by selecting New Project from the File menu. This will display a dialogue box in which you can specify a *project* name and various other features of the *project*. In its expanded state, with the More button selected, the dialogue box is as follows:



The fields are:

Name

The *project* name that will appear in the navigation panel when the new *project* is created.

Comment

A comment about the *project*.

More / Less

This is a toggle button to expand and contract the dialogue box. The following additional fields appear in the expanded state:

Location

The folder in the filing system where the *project* is to be stored, for example:

C:\My Data\ModuLab MTS

Browse

Browse the filing system to find a suitable location for the *project*. The selected folder will appear in the Location field.

Create experiment too

If this box is checked, an *experiment* will be created with the *project*.

Cancel

Close this dialogue box without creating a *project*.

Create Project

Complete the creation of the *project* so that it appears in the left-hand navigation panel. If a *project* is already open, containing items that have changed, the Close Project dialogue box will appear, so that you can specify the items that need to be saved, then the new *project* will appear.

☞ Opening and Closing Projects, Section 5.1.2.

☞ Example of how to create a new *project* and develop an *experiment*, Chapter 3.

5.1.2 Opening and Closing Projects

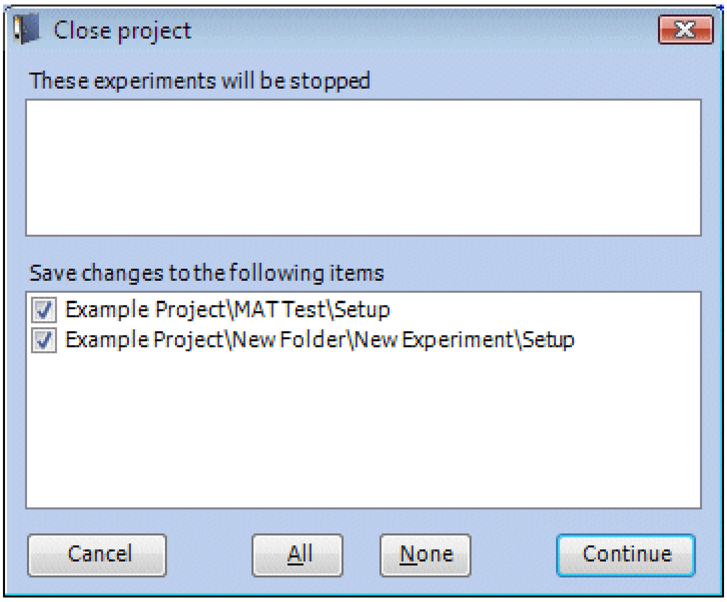
Projects can be opened and closed as follows:

- To open a *project* that has previously been created, select Open Project from the File menu. A filing system dialogue box appears with an appropriate folder selected (depending on previous navigation of the filing system) and you can expand the folder and select the *project* to be opened, then click OK. If a *project* is already open and changes have been made, the Close Project dialogue box will appear so that you can save the changes. Then the new *project* will appear in the navigation panel (with the Project tab selected) in place of any currently open *project*.
- To re-open a recently opened *project*, hold the cursor over Recent Projects in the File menu, to display a recent *project* list, then select the required *project*. If a *project* is already open and changes have been made, the Close Project dialogue box will appear so that you can save the changes. Then the new *project* will appear.

  A project will remain in the recent *project* list until the whole list is cleared using Clear List, which appears at the bottom of the list.
- To close a *project*, select Close Project from the File menu. If changes to the *project* have been made, the Close Project dialogue box will appear so that you can save the changes. All structures will then disappear from the navigation panel, regardless of whether the System or Project tab is selected.

The Close Project dialogue box appears in all circumstances where a project needs to be closed and changes to the project have been made. This includes closing a project yourself, creating a new project or opening an existing project when a project is already open, or exiting the ModuLab XM application.

The dialogue box is as follows:



The fields and controls are as follows:

These experiments will be stopped

This panel contains a list of all experiments that are currently running. All experiments will be stopped when the project closes, because they depend on the project for their setup and collection of data. Normally, you wouldn't want to close a project while an experiment is running, so this serves as a warning that you should click the Cancel button.

Save changes to the following items

This panel contains a list of items in the project where changes have been made, since the project was opened. In each case, the item is identified from the full pathname in the expanded structure in the left-hand navigation panel, and there is a check box so that you can specify that the item needs to be saved.

Cancel

This button closes the dialogue box without closing the project, and without saving any items.

All

This button checks the boxes for all the items in the list, so that they will all be saved when you click Continue.

None

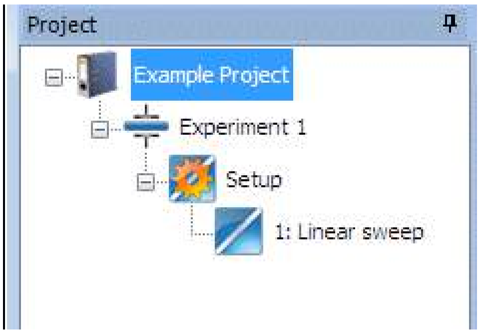
This button clears the boxes for all the items in the list, so that none of them will be saved when you click Continue.

Continue

This button closes the project and saves the changes to the items that have been checked. Any experiments that are currently running will be stopped.

5.2 EXPERIMENTS

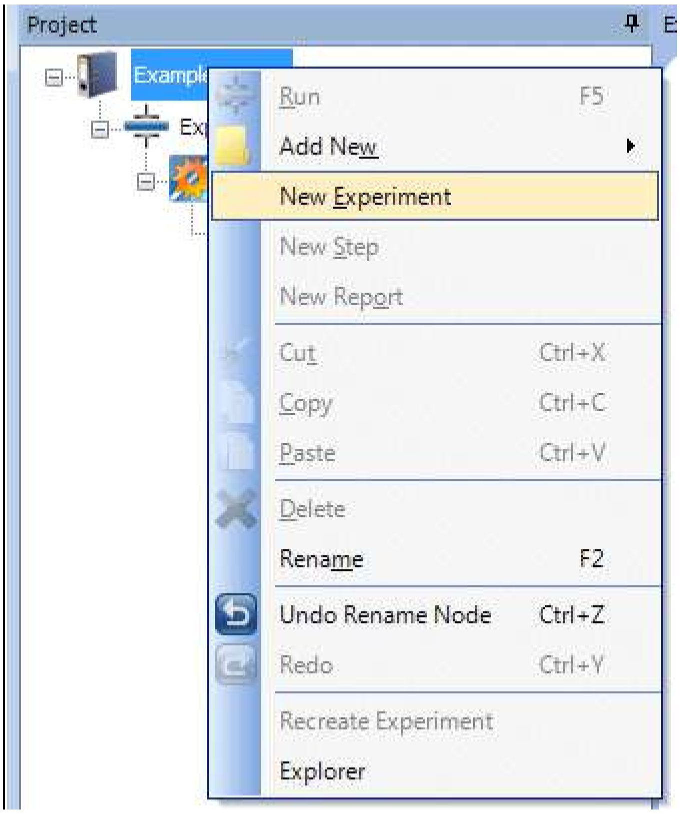
Any number of *experiments* can be set up within a *project*, either directly under the *project* or under a *folder* within the *project*. Underneath each *experiment*, there is a Setup feature, which enables the general features of the *experiment* to be defined, and at the next level there are *steps* and *loops* which define the excitation signals to be applied to the sample during the *experiment*. An *experiment* structure, containing a single *step* called Linear Sweep, is as follows:



5.2.1 Add New Experiment

To add an *experiment* to a *project* or *folder*, proceed as follows:

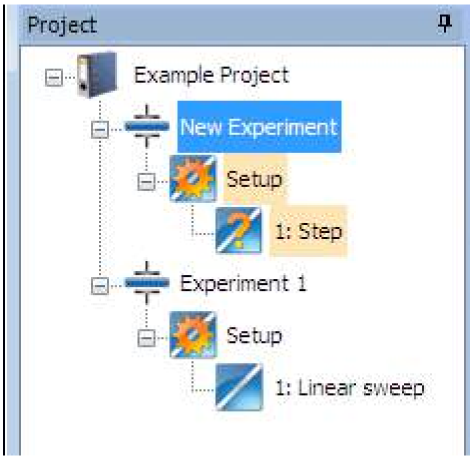
1. Run the ModuLab XM software and open the appropriate *project*.
2. Right-click on the *project* to display the drop-down list box and select New Experiment.



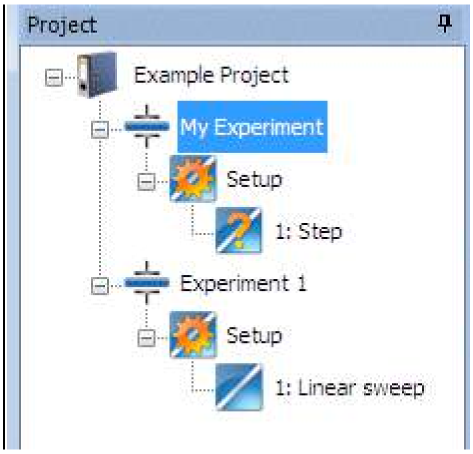
The new *experiment* will appear in the navigation panel and the Start Experiment screen will appear.

☞ Start Experiment, Section 5.2.2.

The *experiment*, in its expanded state, will show its own Setup item as follows:



3. Click once on the new *experiment* to select it, then click again, then type an appropriate name, for example My Experiment, so the navigation panel becomes as follows:



4. Set up the *experiment*.

   ☞ Sections 3.2.2 and 5.3 (including the sub-Sections)

5. Under the Setup item, there is a single *step* called:

   1: Step

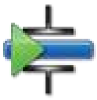
   Assign a *step type*.

   ☞ Section 5.6.2

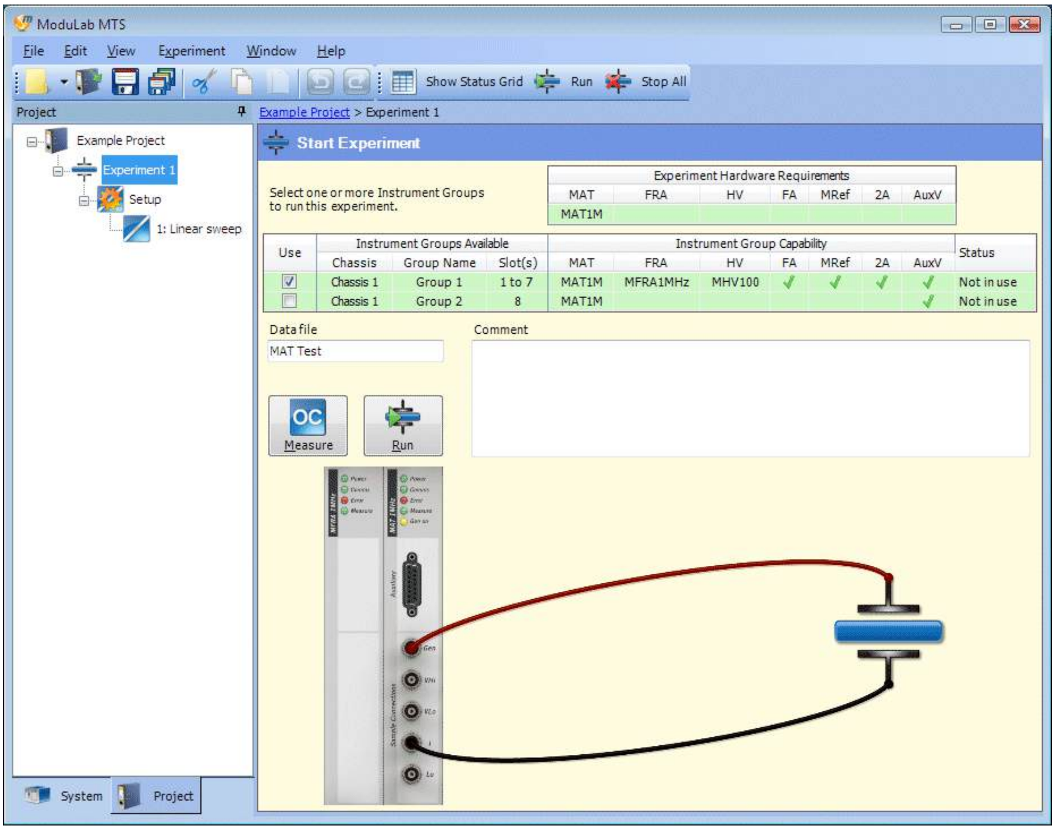
NOTE: It is also possible to add an *experiment* to a *folder* within the *project*, by right-clicking on the *folder*, then selecting Add New, then Experiment. This has a different functionality than New Experiment, because it adds the *item* directly under the currently selected *item*.

☞ Add New in the File menu (Section 2.4.1) and
New Experiment in the Experiment menu (Section 2.4.4).

5.2.2 Start Experiment



When an *experiment* is selected from the navigation panel, the Start Experiment screen appears as follows:



This is the top level screen for the *experiment*, which enables the *experiment* to be run, but first it has to be correctly configured from the lower level screens.

This screen displays the connection diagram, defined in the Hardware Requirements, and there are two tabulated lists of equipment as follows:

- There is a tabulated list of Experiment Hardware Requirements, which specifies the modules that are required for the experiment. A core module will always be required, but additional modules may also be required as follows:
    - A high voltage module, femto-ammeter, sample and reference module or booster (2A) may be required, depending on the experiment type and instrument configuration specified in the Hardware Requirements sub-screen, in the *experiment* setup screen.

      ☞ Hardware Requirements, Section 5.3.2.

- Auxiliary voltage channels will be required if they have been enabled in the Instrument Experiment Setup sub-screen, in the *experiment* setup screen.

  NOTE: Auxiliary channels are fitted as standard to ModuLab XM MTS but may be optional in other versions of ModuLab XM.

  ☞ Instrument Experiment Setup, Section 5.3.4.

- An FRA will be required if an impedance *step* has been defined under the *experiment*.

  NOTE: An FRA is always included in the connection diagram, regardless of whether or not it is used in the experiment.

- There is a tabulated list of installed hardware, matching the Equipment Summary, with the groups identified under Instrument Groups Available, and the module specifications under Instrument Group Capability. Each row of the table represents one *instrument group*, and the row will be coloured green if it matches or exceeds the Experiment Hardware Requirements and is available for running an *experiment*. It will turn red, indicating that it cannot be used, in either of the following circumstances:

  - The *instrument group* fails to meet the Experiment Hardware Requirements. The cells representing equipment that is either missing or not to the required standard will turn a darker shade of red.

  - The *instrument group* is already running an *experiment*. This will already be obvious if the PC and ModuLab XM system are alongside each other in the same room, but not so obvious if they are in different locations on a network. The *instrument group* will turn green when the *experiment* has finished.

  ☞ Equipment Summary (Section 4.2.1).

The tabulated list of installed hardware has an additional field, not included in the Equipment Summary, as follows:

Use

This column contains a check box for each *instrument group*, so that you can select which ones to use for the *experiment*. Any group that meets or exceeds the Experiment Hardware Requirements can be used. An *experiment* can be run using multiple core modules, by checking the boxes for each of them and connecting a sample to each *instrument group*.

The default selection will be a single check box, according to the following rules:

- If the *experiment* has just been added, the box will be checked for the first *instrument group* in the list that meets the requirements.

- If a group has been specified in the Instrument Group to use field, in the Hardware Requirements sub-screen in the *experiment* setup screen, the box for the specified group will be checked.

- If the Custom option has been selected in the Instrument Group to use field, no box will be checked. The Custom option does not depend on any installed hardware, and enables the configuration to be set up so that it can be transported between systems.

Comment

You can write a comment about the *experiment*.

Data File

This field specifies the name of the *data* file that appears in the navigation panel when the *experiment* is run. It defaults to the *experiment* name, and is appended by a number if the same name is used more than once.

OC Measure

This button performs an open circuit measurement on the sample, to obtain results without applying an excitation signal from the generator. The results will appear in the status grid at the bottom of the screen, together with a red control button so that the measurements can be stopped. When the measurements are stopped, the red button is replaced by an OC button so that they can be re-started.

The open circuit measurement is a useful method of obtaining results on the performance of the sample, before running an *experiment*.

Run

This button runs the *experiment* and writes the results to the specified *data* file. The file name appears in the navigation panel, automatically highlighted, and the graphs and tabulated lists of data will appear, and will be updated as each new data point is collected.

(Error and Warning Messages)

If the *experiment* has not been set up correctly, a tabulated list of errors and warnings will appear at the bottom of the screen as follows:

Severity	Description
Error	2: Step: The step is undefined.
Error	3: Run External Program: The program to run does not exist.
Warning	Experiment: No Impedance steps are using the Sample and Reference Measurement Mode.

There are two columns:

Severity

The severity of the problem, which may be:

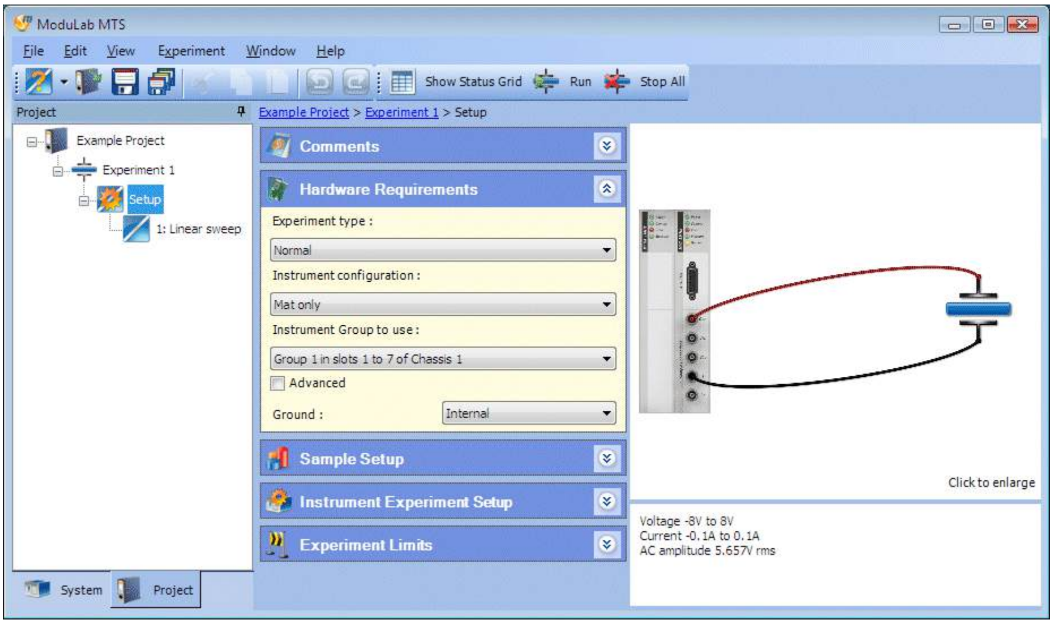
Warning	The *experiment* will run, but there is something in the configuration that doesn't make sense. For example, if the *experiment* uses the Sample and Reference module, but there are no impedance *steps* that use the "Sample & Reference" measurement mode, a warning will appear.
Error	The *experiment* will not run. Instead a message box will appear when you click the Run button, advising you to correct the problems found in this tabulated list of errors.

Description

A description of the problem. The message begins with an identification of where the problem occurs, for example “Experiment” if it’s in the Setup, or the *step* number if it’s in one of the *steps*. Then it says what the problem is about.

5.3 EXPERIMENT SETUP

When you select the Setup item, under an *experiment* in the navigation panel, the *experiment* setup screen appears as follows:

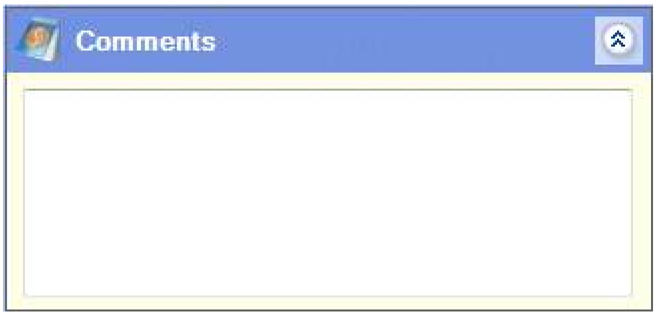


The *experiment* setup screen is divided into the following sub-screens:

- Comments
- Hardware Requirements
- Sample Setup
- Instrument Experiment Setup
- Experiment Limits

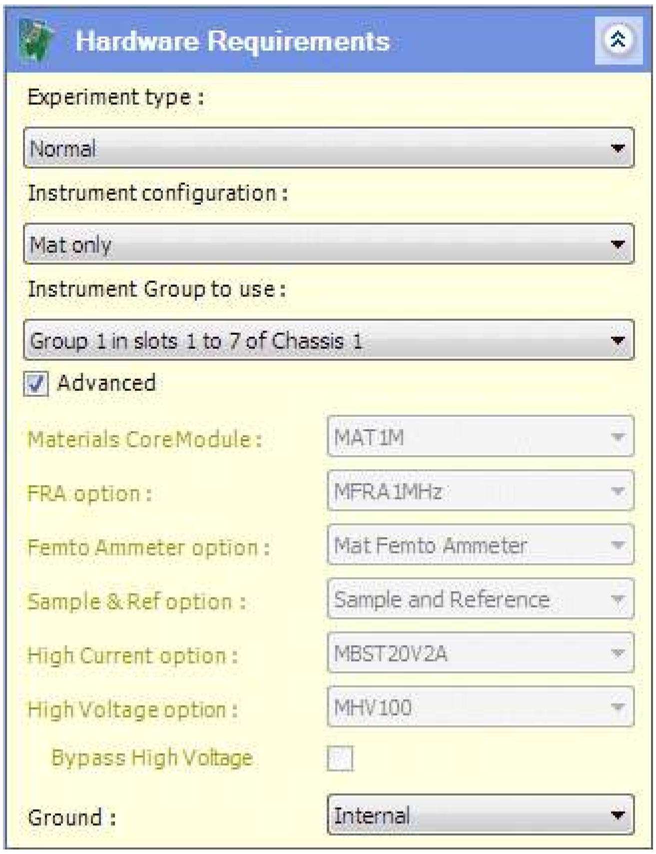
5.3.1 Comments

The Comments sub-screen, in the *experiment* setup screen, enables you to enter a comment about the *experiment*.



5.3.2 Hardware Requirements

The Hardware Requirements sub-screen, in the *experiment* setup screen, specifies the hardware and connection configuration for the *experiment*. The expanded screen with the Advanced box checked is as follows:



The fields are:

Experiment Type

The type of *experiment*, representing a main category in which there can be a number of different hardware and connection configurations. The following options are available from the list box:

Normal
Sample & Reference
Installation Test

The default option is Normal.

Instrument configuration

The modules required for the *experiment*. The available options depend on the selected Experiment type, as follows:

Experiment Type:	Available Instrument configurations
Normal	Mat only Mat + HV Mat + Femto Ammeter Mat + HV + Femto Ammeter Mat + 2A Mat + HV + 2A
Sample & Reference	Mat only Mat + HV Mat + Femto Ammeter Mat + HV + Femto Ammeter
Installation Test	Mat only Mat + HV Mat + Femto Ammeter Mat + Sample & Reference Mat + 2A

A connection diagram and description is displayed when a selection is made from these two list boxes, and the circumstances in which each configuration may be used are given in the Hardware and Connection Configurations.

☞ Hardware and Connection Configurations, Section 3.3, including the sub-Sections.

The default option is Mat only.

Instrument Group to use

The *instrument group* to be used for this *experiment*. The list box contains all the groups installed in the system, according to the names that they have been given in the Instrument Group Setup.

☞ Instrument Group Setup, Section 4.2.3.

If there is more than one *instrument group*, the name will be appended by the slot numbers and chassis number, for example “Group 1” becomes “Group 1 in slots 1 to 7 of Chassis 1”.

The default option is the first group that is found by the system, that matches the requirements of the *experiment*, based on the Experiment type and Instrument configuration. These two fields respectively default to Normal and Mat only, when adding a new *experiment*, so any group could be used in the Instrument Group to use field because they all have a core module. The default is therefore the first group in the chassis, according to their slots, and if a group is not found it defaults to Custom.

The Custom option enables you to set up an *experiment* without necessarily matching it to any specific hardware. For example, you might have problems with the hardware, or you may be changing the hardware configuration, or you may be setting up an *experiment* for a third party system where the installed modules may be different from those in your own system. The Custom option makes the *experiment* fully transportable between systems, and if all the *experiments* in a *project* use this option, it means the *project* is independent of the Equipment library.

Advanced

If this box is checked, the sub-screen expands to display the materials core module and optional modules in the selected Instrument Group to use, according to their model identifiers. If an *instrument group* is selected from the installed hardware, the fields will be greyed out and cannot be changed. Otherwise, if the Custom option has been selected, the list boxes become available for you to select a model.

If the *experiment* requires optional modules, according to the Experiment type and Instrument configuration, and a core module is selected that does not have the optional modules fitted, a red error icon will appear alongside the appropriate module fields. The *experiment* will not run when there is an error.

The following fields appear under the check box:

Materials Core Module

The model of the core module that is being used. There is only one model, as follows:

MAT 1MHz

FRA option

The option to use an FRA if required. There is only one model, so the field may be either of the following:

Not fitted
MFRA 1MHz

Femto Ammeter option

The option to use a femto ammeter if required. There is only one model, so the field may be either of the following:

Not fitted
MFA

Sample & Ref option

The option to use a sample and reference module if required. There is only one model, so the field may be either of the following:

Not fitted
MREF

High Current option

The option to use a 2A booster if required. There is only one model, so the field may be either of the following:

Not fitted
MBST 2A

High Voltage option

The option to use a high voltage module if required. There is only one model, so the field may be either of the following:

Not fitted
MHV 100

Bypass High Voltage

The high voltage module is fitted with a bypass circuit, so that if this box is checked, the signal passes through the module unchanged.

This box can be checked only if a high voltage module is available and is used in the *experiment*, otherwise it is greyed out. The High Voltage option field must indicate a model, and the Instrument configuration field must include a high voltage module (for example Mat + HV).

Ground

The type of grounding to be used. The options are:

Internal — The ModuLab XM system is internally grounded, with the LO point connected to ground through an internal switch (no cable required). This option should only be used if the sample is not grounded.

External — The ModuLab XM system is externally grounded through the sample (LO floating). This option should only be used if the sample is grounded.

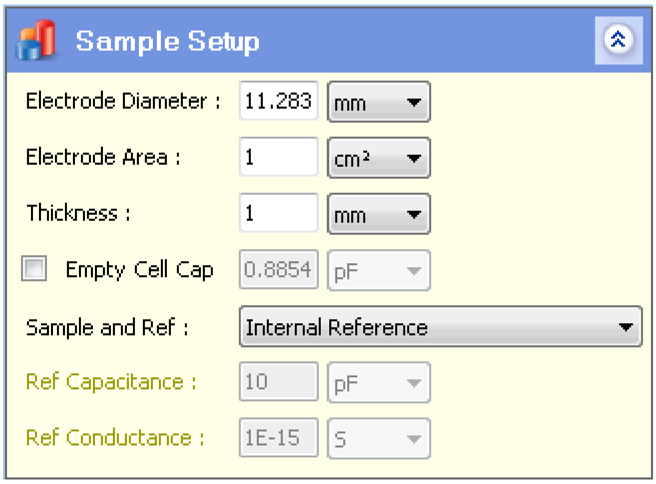
An amber warning icon appears if the selected grounding is inappropriate for the *experiment*.

NOTE: The LO point is a common reference voltage for modules within a group.

☞ Installation Guide.

5.3.3 Sample Setup

The Sample Setup sub-screen, in the *experiment* setup screen, specifies the sample configuration for the *experiment* as follows:



The fields are:

Electrode Diameter

The diameter of the sample electrode. A value specified in this field will cause the Electrode Area to be calculated and highlighted in green.

Electrode Area

The area of the sample electrode, used for the calculation of current density. A value specified in this field will cause the Electrode Diameter to be calculated and highlighted in green.

Thickness

The thickness of the sample, used to calculate permittivity and modulus.

Empty Cell Cap

The capacitance of the empty space between the sample holder electrodes, when there is no sample between them.

If the box is checked you can specify a value.

If the box is unchecked, the field will be greyed out and will display a value calculated from the Electrode Area and Thickness.

Sample and Ref

The sample and reference module may be configured to use it's own internal reference capacitors, or it can be connected to an external reference supplied by the user. The options are:

Internal Reference	The sample and reference module is configured to use it's own internal references. The connection diagram will show the Ref sockets connected to the Int Ref sockets (Figure 5-1).
User Reference	The sample and reference module is connected to an external reference, supplied by the user. The connection diagram will show the Ref sockets connected to the external user reference (Figure 5-2).

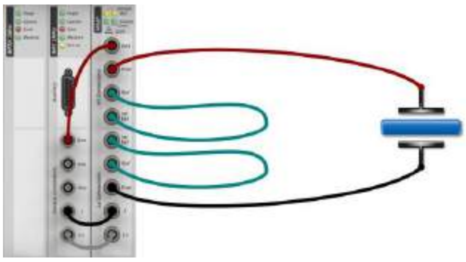


Figure 5-1 Sample and reference module with internal reference

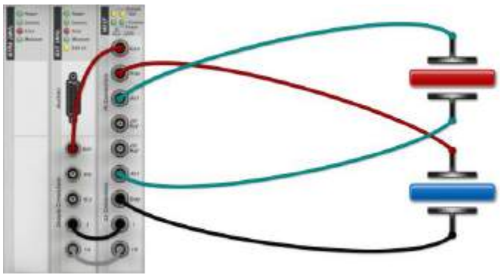


Figure 5-2 Sample and reference module with user reference

The following fields become available when User Reference is specified in the Sample and Ref field, otherwise they are greyed out. They specify the properties of the external user reference.

Ref Capacitance

The capacitance of the user reference.

Ref Conductance

The conductance of the user reference, measured in Siemens.

☞ These fields are only applicable when Sample & Reference has been specified as the Experiment Type, in the Hardware Requirements, Section 5.3.2, and Sample & User Ref has been specified as the Measurement Mode, in the Impedance Setup, Section 5.7.1.

5.3.4 Instrument Experiment Setup

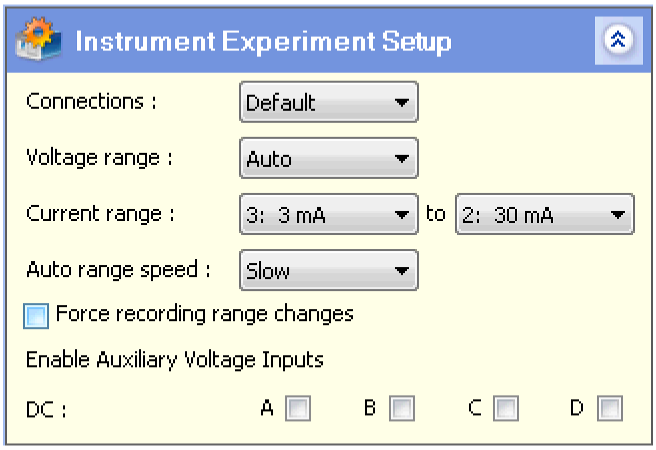
The Instrument Experiment Setup sub-screen, in the *experiment* setup screen, specifies the instrument configuration for the *experiment* as a whole. A more specific setup is available for *steps* within the *experiment*, from the Instrument Step Setup.

☞ Section 5.7.4.

NOTE: These setup screens are for the *experiment* and *step*. There is also an Instrument Group Setup for the hardware, defined in the Equipment library.

☞ Instrument Group Setup, Section 4.2.3.

The Instrument Experiment Setup screen is as follows:



The fields are:

Connections

The number of connections to the sample. The options are:

Default	The connections are 2 Terminal or 4 Terminal, depending on the Experiment Type and Instrument Group to Use, specified in the Hardware Requirements. ☞ Hardware Requirements, Section 5.3.2.
2 Terminal	Only the generator (Gen) and current return (I) are connected to the sample. This configuration is always used for experiments that use the Sample and Reference module.
4 Terminal	The generator, current return and two voltage measurement connectors (Vhi and Vlo) are connected to the sample. This configuration is always used for experiments that use the 2A booster module.

Voltage range

The voltage range of the core module. The options are:

Auto
0: 8V
1: 3V
2: 300mV
3: 30mV
4: 3mV

Each range, other than Auto, is prefixed by a range number so that the ranges can be recorded and displayed with the data.

The default value is Auto, displayed in a single list box and this selects a voltage range appropriate to the measurements. If any other value is selected, a second list box appears so that you can specify an upper value of the voltage range.

Each value represents a range, so that a pair of values represents the limits of the ranges to be used. For example, if the first list box specifies 300mV and the second one specifies 8V, the system will switch between three ranges as required (300mV, 3V, 8V). To maintain the core module on a fixed range, both list boxes have to be the same.

If the auxiliary channels are enabled, they will find their own voltage ranges within the limits set for the core module.

Current range

The current range of the core module. The options are:

Auto
1: 100mA
2: 30mA
3: 3mA
4: 300µA
5: 30µA
6: 3µA
7: 300nA
8: 30nA

Each range, other than Auto, is prefixed by a range number so that the ranges can be recorded and displayed with the data.

If any value other than Auto is selected, a second list box appears so that you can specify an upper value of the current range. A pair of values represents the limits of the ranges to be used, same as for the Voltage range.

The default value is Auto, displayed in a single list box, and this selects a current range appropriate to the measurements. The range should be limited by a pair of values in cases where Auto would give inappropriate ranges or an excessive number of changes in range.

Auto range speed

This feature is available to limit the speed at which current range changes can occur, for example when the measurements pass through zero or the data is noisy. The options are:

Fast
Medium
Slow
Very Slow

The appropriate option should be selected, depending on how it affects the collection of data. The faster options may produce an excessive number of range changes, while the slower options may occasionally use a less accurate range.

Force recording range changes

When an experiment is running and generating data, and the core module changes from one voltage or current range to another, the system may record the range numbers so that they can be displayed in graphs and tables, together with the data.

Normally, range numbers are only included in the data when the measurement rate is less than 500 samples/second. However, if this box is checked, range numbers will be included at higher measurement rates, even if it slows down the collection of data.

☞ Measurement Ranges, Section 5.11.2, for details of how to display range information with the data.

Enable Auxiliary Voltage Inputs

This group of fields determines how the auxiliary channels are to be used in the *experiment*. These channels are for connection to accessories such as temperature probes, not for taking measurements on the sample.

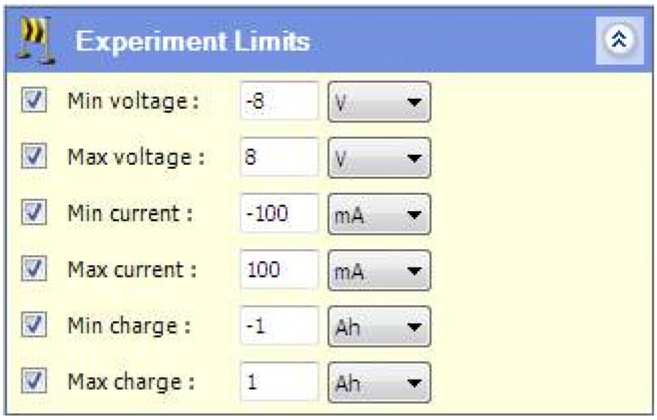
DC

The four check boxes, A, B, C, D, indicate the auxiliary channels that are used for DC measurement.

☞ Installation Guide, for details of auxiliary channel cable connections and grounding.

5.3.5 Experiment Limits

The Experiment Limits sub-screen, in the *experiment* setup screen, specifies the upper and lower limits of voltage, current and charge to be output to the sample, as follows:



To apply a limit, check the appropriate box, then specify the value and units from the associated numeric field and drop-down list box.

NOTE: Experiment limits are also imposed by the ModuLab XM hardware. The Materials Core Module is fitted with short circuit protection so that a switch opens when the current reaches an unsafe level. If this happens, the Error (red) LED on the module front panel will come on, but it is unlikely to happen because of various built-in safeguards.

☞ Installation Guide.

If a limit is reached during an *experiment*, whether imposed by the hardware or software, the appropriate cells in the status grid will turn red and the *experiment* will pause, but it can be made to continue under appropriate circumstances using the control buttons at the right of the status grid.

☞ Paused Experiments, Section 2.6.1.

5.4 LOOP

A *loop* defines a set of measurements to be taken repeatedly, and may contain additional *loops*, nested at multiple levels. Measurements are taken by including *steps* within the *loops*.

5.4.1 Adding a Loop

In the navigation panel, a *loop* can be added under an *experiment* Setup or another *loop* as follows:

1. Right-click on the *experiment* Setup or *loop* to display the drop-down menu. Move the cursor to Add New, then select Loop. The new *loop* appears under the *experiment* Setup or *loop*, prefixed by a number, for example:

   1: Loop

   The number is incremented by 1 for each successive *loop* at the same level. However, *loops* and *steps* belong to the same sequential numbering system, so that if there is already a *step* at the same level and you add a *loop*, it will be given the next number, for example:

1: Step
2: Loop

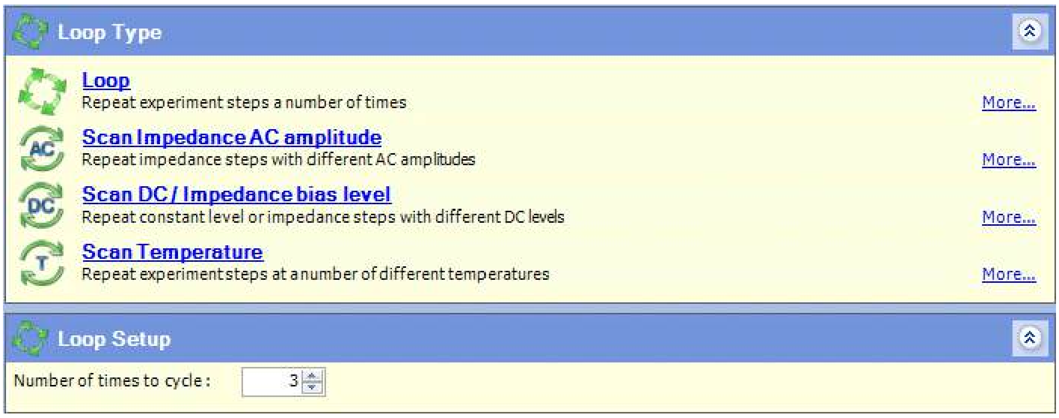
2. Add some more *loops* or *steps* under the *loop*. You can add as many nested *loops* as you like, but there has to be some *steps* within the structure, otherwise the *loop* doesn't do anything.

NOTE: *Decisions* can also be included in the structure of *loops* and *steps*.

☞ Decision, Section 5.5.

5.4.2 Loop Setup

When you click on a *loop* in the navigation panel, the Loop Type and corresponding Loop Setup are displayed as follows:



The Loop Setup sub-screen depends on the selected Loop Type. The default is Loop and the sub-screen has a single field:

Number of times to cycle

When the *experiment* is run, it will cycle round the *loop* the specified number of times, implementing all the *steps* and sub-*loops* each time round.

The remaining fields in the Loop Type sub-screen are for setting up scanning *loops*, where the *steps* use AC amplitude or DC bias levels from the *loop*.

☞ Loop Types, Section 5.9.

5.5 DECISION

A *decision* enables the instrument to optionally run a sequence of *steps*, from a choice of alternatives, depending on the state of the sample at the end of the previous *step*.

The following schematic shows an example of how a *decision* might be used.

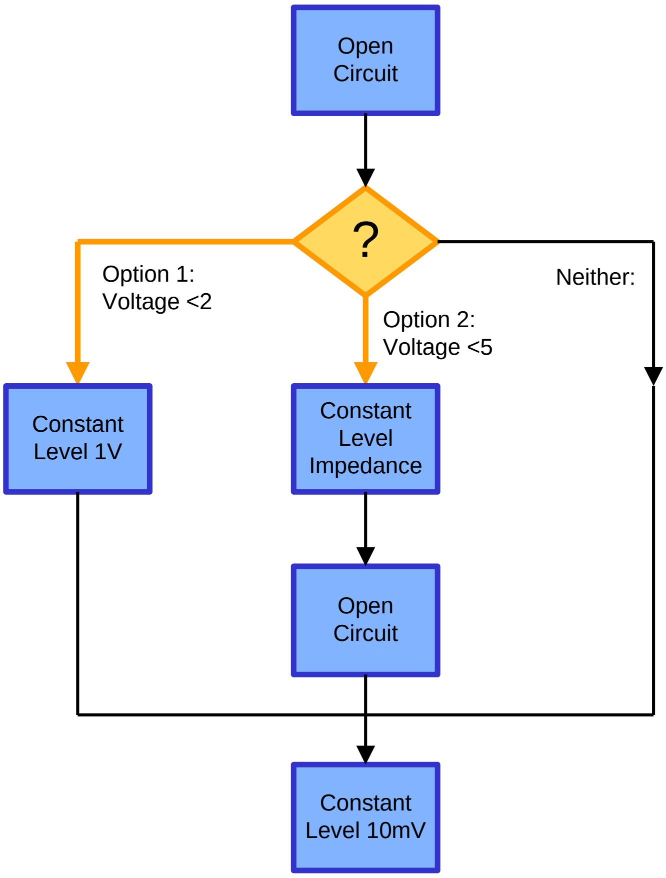


Figure 5-3 Schematic diagram of decision process

In this example, the *decision* is based on the last measurement of an Open Circuit *step*, and there are three possible outcomes, depending on the result:

- Option 1 is evaluated first, and if the Open Circuit measurement is less than 2V, the *step* within the *option* is performed, in this case Constant Level at 1V.
- If the Open Circuit measurement is greater than 2V, Option 2 is evaluated, and if the result is less than 5V, the *steps* within the *option* are performed, in this case a Constant Level Impedance *step* followed by an Open Circuit *step*.
- If neither of the conditions are met, because the result is greater than 5V, none of the *steps* in Options 1 or 2 are performed.

Finally, at the end of the decision process, regardless of the result, the system proceeds to the next *step* in the *experiment*, which is Constant Level at 10mV.

The corresponding structure in ModuLab XM is as follows:

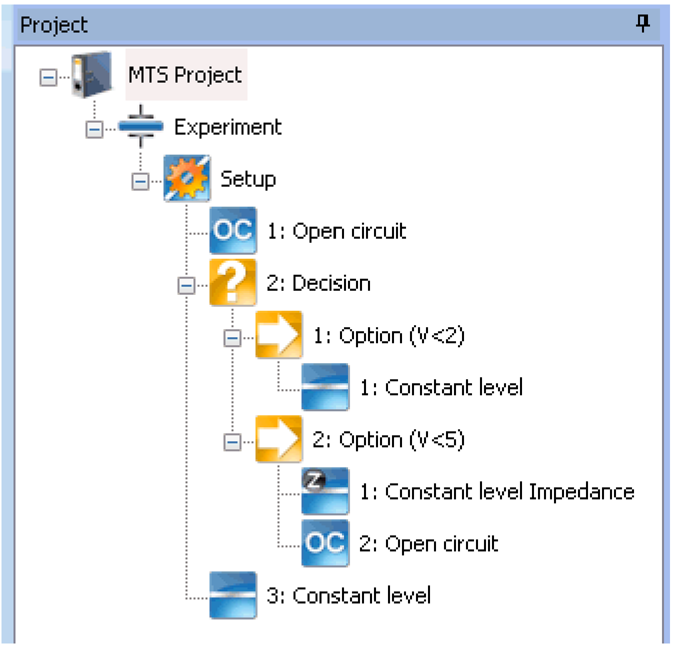


Figure 5-4 Navigation panel corresponding to decision process

A *decision* may contain any number of *options*, each with a set of conditions to be tested. The *options* are performed from top to bottom, first Option 1, then Option 2, and so on. As soon as the conditions for an *option* are fulfilled, the *steps* under that *option* are performed and then the system goes to the end of the decision process, ignoring all further *options*.

The conditions to be tested within an *option* are specified in the Option Conditions sub-screen.

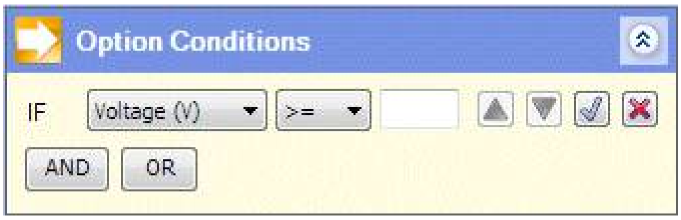
☞ Decision Option Conditions, Section 5.5.1, based on the Step Termination, Section 5.7.3.

A *decision* can be added to an *experiment*, using the drop-down menus associated with the *items* in the usual way. The rules for creating decision structures are as follows:

- A *decision* can be added under an *experiment* Setup, a *loop*, or an existing *decision option* if there is one.
- A *decision* has to be preceded by at least one *step*, somewhere in the *experiment* structure, so that there are measurements on which the *decision* can be based.
- *Decisions* can be nested up to eight levels.
- There has to be at least one *step* within the structure under each *option*, otherwise it doesn't do anything.

5.5.1 Decision Option Conditions

When you click on a decision *option* element in the navigation panel, the Option Conditions screen is displayed as follows:



This screen specifies a single test to be performed, according to the entries you make in the fields, and you can add more tests using the AND / OR buttons. The fields and buttons in this screen are described in detail under Step Termination, which has similar functionality.

☞ Step Termination, Section 5.7.3.

5.6 STEP

A *step* defines an excitation signal to be applied to the sample, in terms of a voltage or current, and a set of measurements to be taken. A variety of different *step types* are available, divided into the following categories:

General
Voltage Waveforms (DC)
Voltage Controlled Impedance (AC, C-V, Mott-Schottky)

5.6.1 Add a New Step

When a new *experiment* is added to a *project* or *folder*, it always contains a single *step* called:

1: Step

This can be assigned a *step type*, but you can add new *steps* to the *experiment* and each of them will be given a sequential number.

☞ Add New Experiment, Section 5.2.1.

☞ Assign a Step Type, Section 5.6.2.

Steps can also be added under *loops*, so that they are repeated according to the specified number of cycles.

To add a *step* under an *experiment* Setup or *loop*, proceed as follows:

1. Right-click on the *experiment* Setup or *loop* to display the drop-down menu and select Add New, then Step. An item appears under the *experiment* Setup or *loop* called:

   n: Step

   The number *n* depends on the number of items that already exist at the same level, which may be *steps* or *loops*, and is incremented by 1 for each successive addition.

The new *step* will be highlighted in the Navigation Panel, and the system displays the categories of *step types* as follows:

☞ Step Types, Section 5.8.

NOTE: It is also possible to add a *step* by selecting New Step from the drop-down menu, instead of Add New, then Step. However, if a *loop* is selected, the *step* will be added directly under the *experiment* Setup, outside of the *loop*.

☞ Add New in the File menu, Section 2.4.1 and New Step in the Experiment menu, Section 2.4.4.

5.6.2 Assign a Step Type

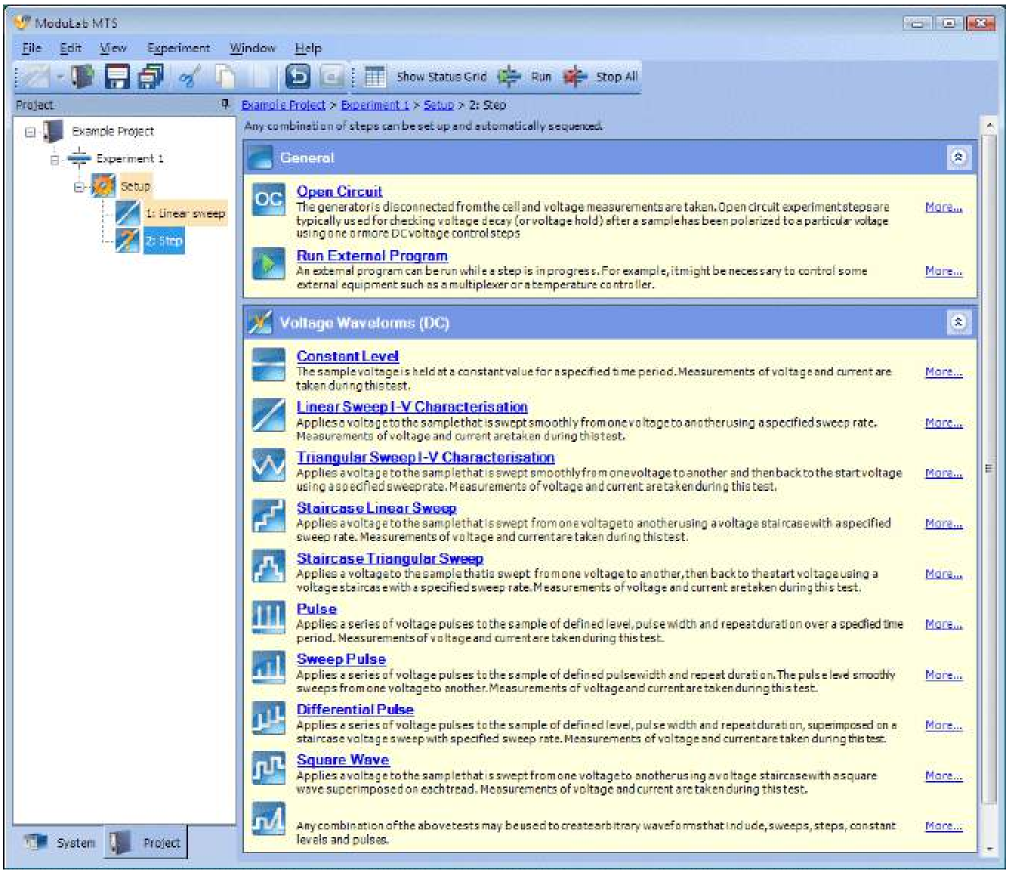
When a new *step* appears in a *project*, as part of a new *experiment*, or because it has been added, it has to be given a *step type* before it can be used.

To assign a *step type*, proceed as follows:

1. Click on the item labelled *n*: Step in the Navigation Panel (where *n* is the sequential item number), to display the categories of *step types*.

   ☞ Add a New Step, Section 5.6.1.

2. Expand the sub-screens to display the *step types* in the appropriate categories as follows:

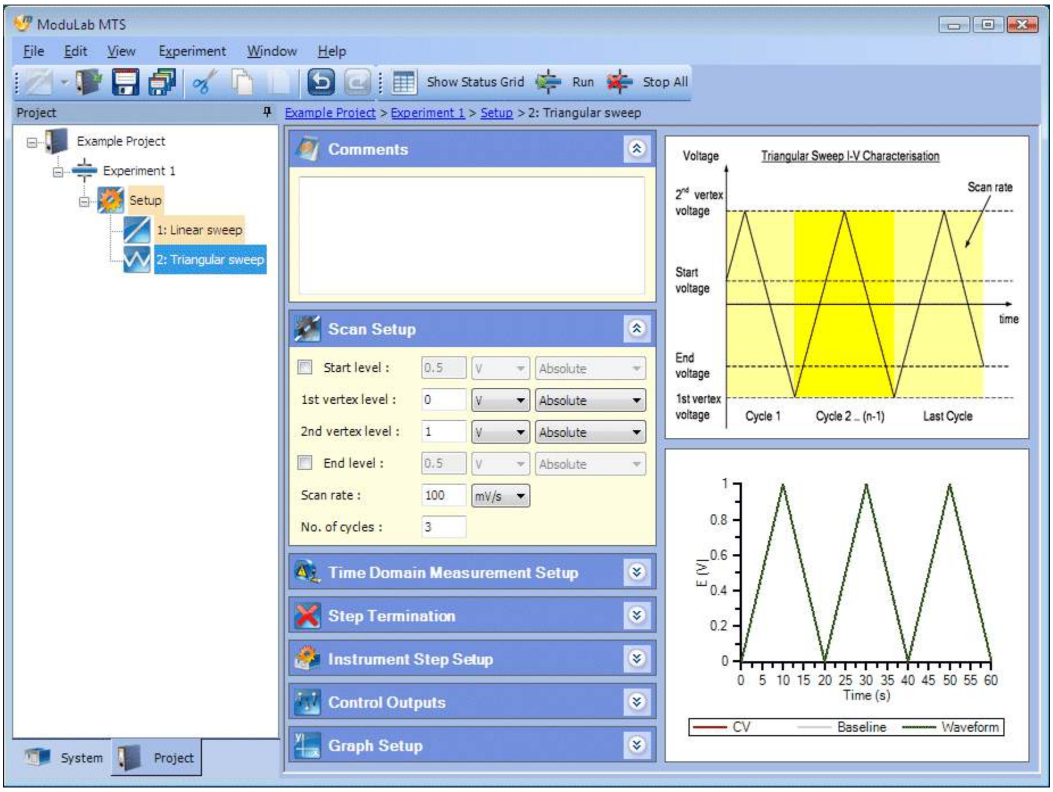


3. Click on the required *step type*. An appropriate screen will appear so that you can specify the detailed configuration, and the item name will change to the chosen *step type*.

4. Configure the *step* as described in the Step Setup (next section).

5.7 STEP SETUP

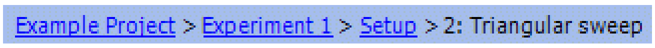
The screens for each *step type* are all slightly different, but they have the same general layout, in the Step Setup screen as follows:



The main window (to the right of the navigation panel) is divided into two sections:

- The left column is a set of sub-screens that you can expand and collapse, and they vary according to the *step type*.
- The right column is a set of graphs, for illustration and setup purposes only. They also vary according to the *step type*, but they do not represent any actual data. The upper graph shows the excitation waveform and the lower graph shows a typical result that might be obtained.

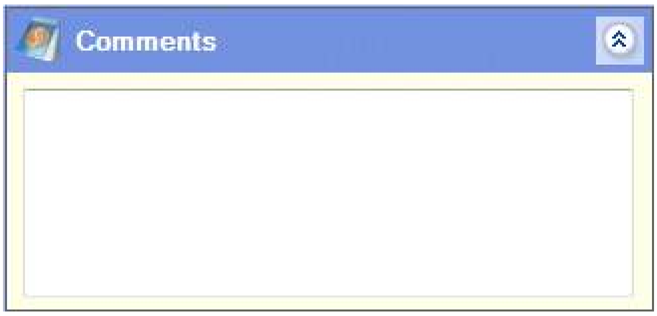
NOTE: The term Step Setup is used as a generic term in this documentation, although it does not appear in the software. Instead, the screens are identified by their *step type* at the top of the column of sub-screens, for example Triangular Sweep, as follows:



The sub-screens are as follows:

Comments

This sub-screen is the same for all *step types* and enables you to enter a comment about the *step*.



Scan Setup

This sub-screen specifies values associated with the excitation signal that is applied to the sample. The shape of the waveform varies according to the *step type* and there are a number of variations of this sub-screen.

☞ Scan Setup, Section 5.8.4 and its sub-sections.

☞ Temperature Settling Step, Section 5.9.3.1.

Impedance Setup

This sub-screen appears only for *step types* that use impedance, and specifies the frequency range to be tested.

☞ Impedance Setup, Section 5.7.1.

Time Domain Measurement Setup

This sub-screen specifies how measurements are to be taken during an *experiment*.

☞ Time Domain Measurement Setup, Section 5.7.2.

Step Termination

This sub-screen specifies the conditions under which the *step* is terminated, using tests on the measured values (voltage, current, etc).

☞ Step Termination, Section 5.7.3.

Instrument Step Setup

This sub-screen specifies an instrument configuration for the *step*, including the voltage and current range. This setup takes priority over the more general Instrument Experiment Setup.

☞ Instrument Step Setup, Section 5.7.4, and Instrument Experiment Setup, Section 5.3.4.

Control Outputs

This sub-screen operates the Control Outputs on the ModuLab XM rear panel, which can be used to control external devices such as heaters, stirrers, flow controllers and fans.

☞ Control Outputs, Section 5.7.5.

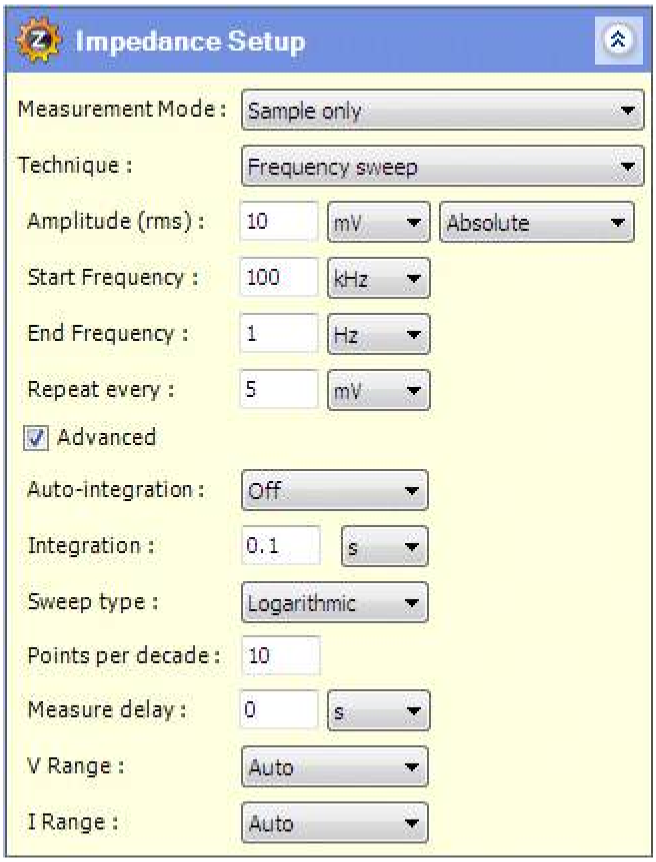
Graph Setup

This sub-screen specifies the graphical display of data generated by the *step*.

☞ Graph Setup, Section 5.7.6.

5.7.1 Impedance Setup

This sub-screen in the Step Setup screen exists only for AC *step types*. The system superimposes a frequency, or a range of frequencies, on top of the DC scan that has been specified from the Scan Setup.



The fields are:

Measurement Mode

This field configures the step to use the Sample and Reference module, according to the following options:

Sample only	Measurements are taken from the sample without using the Sample and Reference module.
Sample & Reference	Measurements from the sample are compared with measurements from known reference capacitors, which may be internal or supplied by the user.

This option should only be used when the Experiment Type, in the Hardware Requirements, is Sample & Reference, otherwise the following error message will appear when you try to run the experiment:

Sample & Reference Measurement Mode can only be used in Sample & Reference experiments.

☞ Hardware Requirements, Section 5.3.2.

☞ The choice between internal and user references is made in the Sample Setup, Section 5.3.3.

Technique

The type of AC stimulus applied to the sample. The options are:

Single frequency	A single sinewave is applied to the sample at a fixed frequency.
Frequency sweep	A single sinewave is swept from the start frequency to the end frequency.
Multisine	Multiple sinewaves, according to a Fast Fourier Transform, are swept from the start frequency to the end frequency.

Amplitude (rms)

The RMS amplitude of the AC signal, maintained at a fixed level during the *step*. The units are:

μV
mV
V

The Relative Values field associated with this field contains the following options:

Absolute	The value is specified in absolute terms without reference to any other values.
AC Scan Value	The value has been specified in the Loop Setup for an AC amplitude scanning *loop*, so that it can be applied

to impedance *steps* within the *loop*. There is no need to specify a value here and the fields will be greyed out.

This option should only be used for a *step* that is inside an AC amplitude scanning *loop*.

☞ Section 5.9.1.

Frequency

The frequency of the AC stimulus. If the Technique is Single frequency, this is a single field (with a units field). If the Technique is Frequency sweep or Multisine, there are two fields representing the Start Frequency and End Frequency of the sweep. The following units are available on all frequency fields:

µHz
mHz
Hz
kHz
MHz
ω

Repeat every

This field exists only for linear sweeps, including cyclic sweeps such as Triangular Sweep, and defines the DC voltage interval for the start of each new impedance measurement.

Start delay

This field appears for non-linear sweeps, including non-linear cyclic sweeps such as Staircase Triangular Sweep, and specifies the delay after every change in DC voltage, before an impedance measurement is taken. It also appears in the case of Constant Level, and the delay occurs only once, at the beginning.

Advanced

The following additional fields appear if this box is checked.

Auto-integration

The signal applied to the FRA can be integrated to reject noise. The effect is to narrow the measurement bandwidth and thus increase the signal to noise ratio. Integration increases the measurement time, so there is a trade-off between the accuracy you require and the measurement speed.

Auto-integration can be used when there is uncertainty about the degree of interference generated by the sample, so that the integration time is adjusted automatically to obtain a specified statistical accuracy in the measurement result.

Auto-integration selects an integration time appropriate for the interference from the noisiest input, and measurement continues until the standard deviation of the input data is reduced to a target value.

The options in this field are:

Off	Auto-integration is not applied, and instead you can specify an Integration Time.
Long	Aims for a standard deviation of ±1% of reading ± 0.001 % of full scale on the noisiest input.
Short	Aims for a standard deviation of ± 10 % of reading ± 0.001 % of full scale on the noisiest input.

Integration

When auto-integration is off, this field can be used to specify a fixed integration time. The units can be seconds or cycles, and a value in seconds is rounded up to cover the nearest number of whole cycles.

When auto-integration is on (long or short), this field specifies the maximum time allowed to reach the required accuracy, although there will always be at least three cycles.

Sweep type

The method of variation of frequency during the sweep. This field only exists when the Technique is Frequency Sweep. The options are:

Linear
Logarithmic

Points

The number of measurement points during a linear sweep. This field only exists when the Technique is Frequency Sweep and the Sweep Type is Linear.

Points per decade

The number of measurement points per decade during a logarithmic sweep. This field only exists when the Technique is Frequency Sweep and the Sweep Type is Logarithmic.

Harmonics

This field is available when the Technique is set to Multisine, and the list box opens up a dialogue box where you can specify the stimulus to the sample in terms of a list of harmonic frequencies to be added to the fundamental frequency. The list of harmonics is returned to the list box as one of the following options:

Pseudo-log
All
Custom

☞ Impedance Setup - Harmonics, Section 5.7.1.1.

Measure delay

A measurement delay can be used in swept sine analyses, to allow the sample to stabilise after a frequency change before the next measurement begins. The units range from µs to days. This field only exists when the Technique is Frequency Sweep or Multisine.

V Range

This field sets the internal voltage range to be used by the FRA.

The options are:

Auto
3mV
30mV
300mV
3V

I Range

This field sets the internal range of the FRA when measuring voltages that represent a current in the core module.

The options are:

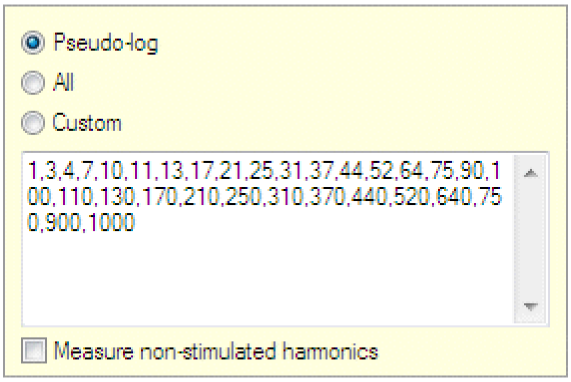
Auto
3mV
30mV
300mV
3V

5.7.1.1 Impedance Setup – Harmonics

In the Impedance Setup, a Harmonics field is available when the Technique is set to Multisine, so that you can specify the harmonics to be added to the fundamental frequency.

☞ Impedance Setup, Section 5.7.1.

When you click on the Harmonics list box, a dialogue box appears as follows:



There are three radio buttons, and the selected option appears in the list box when the dialogue box is closed. There is a text box below the radio buttons, giving the list of harmonics associated with the selected option.

The fields are as follows:

Pseudo-log

This radio button selects a list of harmonics which is approximately logarithmic over three decades from 1 to 1000.

All

This radio button selects the complete set of harmonics from 1 to 1024.

Custom

This radio button enables you to create your own harmonics by editing the list.

(Text box)

This text box displays the list of harmonics associated with the selected radio button. The number 1 is the fundamental frequency, and all the others are multiples of the fundamental frequency.

Measure non-stimulated harmonics

When this box is checked, the system measures all harmonics generated from the sample, regardless of whether or not they belong to the specified list of harmonic frequencies.

5.7.2 Time Domain Measurement Setup

This sub-screen, in the Step Setup screen, specifies how DC measurements are to be taken during an *experiment*. The available fields depend on the selection from the first field as follows:

Measurement mode

This field specifies whether measurements are to be taken on a regular basis, or when there are changes to the sample excitation. The options, according to the *step types*, are:

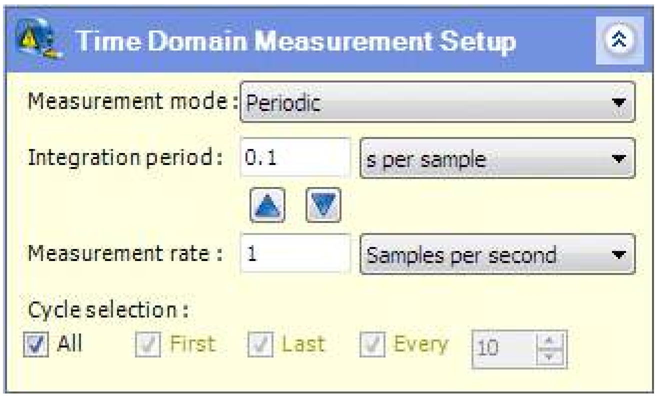
Option	Available for *step types*:	Default for *step types*:
Periodic	All *step types*	Open Circuit Run External Program Temperature Settle Constant Level Constant Level Impedance
V change	Open Circuit Run External Program Temperature Settle Linear Sweep Impedance Triangular Waveform Impedance All DC *step types* except Constant Level	Linear Sweep Triangular Sweep Linear Sweep Impedance Triangular Waveform Impedance
I change	Run External Program Temperature Settle All DC *step types*	None
Per pulse	Sweep Pulse Differential Pulse Square Wave Pulse	Sweep Pulse Differential Pulse Square Wave Pulse
Per step	Staircase Linear Sweep Staircase Triangular Sweep Staircase Linear Sweep Impedance Staircase Triangular Waveform Impedance	Staircase Linear Sweep Staircase Triangular Sweep Staircase Linear Sweep Impedance Staircase Triangular Waveform Impedance

NOTE: The Time Domain Measurement Setup sub-screen specifies Measurement mode options for both AC and DC *steps*. This is because impedance measurements are taken by superimposing a frequency on a DC scan.

☞ Impedance Setup, Section 5.7.1.

The screens for each of these options are as follows:

- **Measurement mode: Periodic**



This screen defines how periodic measurements are taken at specified intervals. The fields are:

Integration period

The integration period for noise reduction purposes. A short period displays a detailed response to the waveform, but it may be affected by noise. A longer period gives less detail but filters out noise.

The integration period can be specified in the following units:

µs per sample	
ms per sample	
s per sample	
Mains cycle	The duration of a cycle of the mains power supply, based on the Mains Frequency specified in the General Settings of the User Preferences ☞ Section 4.1.1.

These two buttons set the Integration period to match the Measurement rate and vice-versa.

The Integration period should not exceed the Measurement rate (as a time interval).

Measurement rate

The rate at which periodic measurements are taken, specified as an interval (seconds) or a frequency (per second).

Cycle selection

These check boxes select the cycles in which measurements are to be taken in a cyclic *step* such as Triangular Sweep. For non-cyclic *steps*, these check boxes do not appear. The options are:

All

Take measurements during all cycles.

First

Take measurements during the first cycle, regardless of whether or not All has been checked.

Last

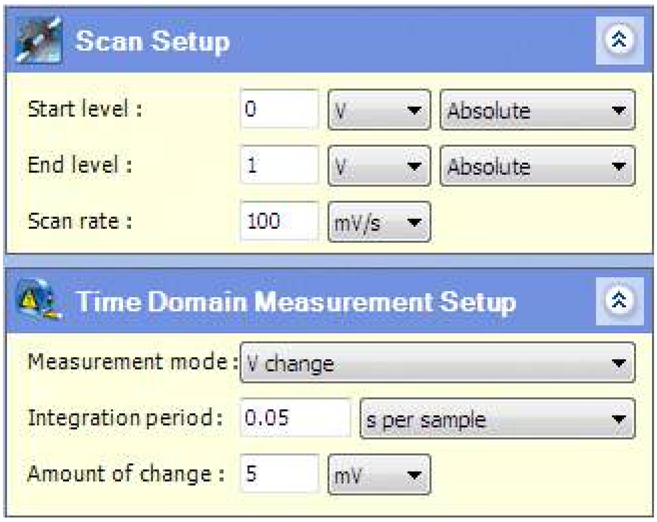
Take measurements during the last cycle, regardless of whether or not All has been checked.

Every *n*

Take measurements every *n* cycles, according to the specified value. If the First box has been checked, measurements will be taken on the first cycle, otherwise the system will wait (*n*-1) cycles and then take measurements on the *n*th cycle.

- **Measurement mode: V change / I change**

For these measurement modes, the type of Time Domain Measurement Setup sub-screen depends on whether or not it is possible to define the measurement rate by comparing the amount of change per measurement with the Scan rate specified in the Scan Setup sub-screen. For example, the Scan Setup screen for a linear sweep and the corresponding Time Domain Measurement Setup screen with the Measurement mode set to V change is as follows:

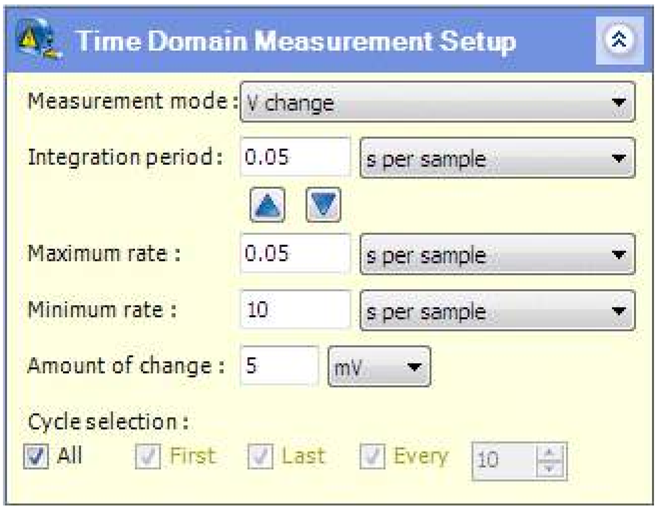


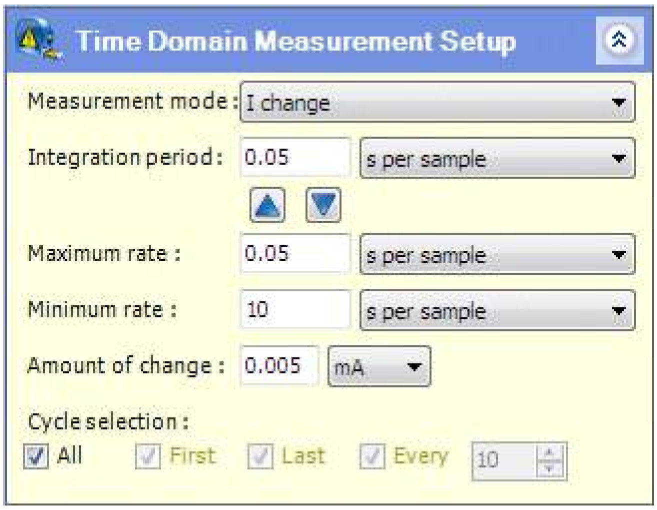
☞ Linear Sweep I-V Characterisation, Section 5.8.4.7.

The measurement rate is the Scan rate divided by the Amount of change, and in this example it works out at 20 measurements per second. When expressed as an interval, this becomes one measurement every 0.05 seconds, and this is the maximum Integration period that the system will use. If the specified Integration period exceeds this value, the system will ignore it and use the calculated maximum.

This type of calculation can only be performed for *step types* that have linear sweeps, including linear cyclic sweeps such as Triangular Sweep, but excluding sweeps where something else is superimposed on a linear scan. For example, staircase scans are not suitable for this calculation, even though they have a Scan rate field in the Scan Setup, because the measurements are dependent on the steps.

If the measurement rate cannot be calculated from the Scan rate and Amount of change, it has to be calculated from other values in an expanded Time Domain Measurement Setup screen, for voltage or current as follows:





In this case, the Maximum rate is the rate at which the system takes measurements for internal use, but if multiple measurements occur at similar values, they will not be reported until a significant change occurs, defined by the Amount of change. In this case, the Integration period should not exceed the Maximum rate.

The fields for the Measurement mode options V change and I change are as follows:

Integration period

The integration period for noise reduction purposes. The value is limited to the calculated measurement rate or the specified Maximum rate, as follows:

- If the Scan Setup and Measurement mode are suitable for calculation of a measurement rate from the Scan rate and Amount of change, the maximum Integration period is limited to the calculated measurement rate (expressed as a time interval).

- If the measurement rate cannot be calculated from a Scan rate and Amount of change, the Integration period is limited to the Maximum rate (expressed as a time interval).

In either case, a value of the Integration period that exceeds the limit will be ignored.

☞ Integration period for Measurement mode: Periodic.

These two buttons set the Integration Period to match the Maximum Rate and vice-versa.

Maximum rate

The rate at which data points are collected by the system for internal use, regardless of whether or not they are reported to the user as measurements. All data points are used as measurements when the sample excitation is changing rapidly, so the measurement rate becomes the Maximum rate.

Minimum rate

The rate at which measurements are taken when the sample excitation does not change sufficiently to trigger a measurement (although the system continues to collect data for internal use regardless of whether or not they are reported as measurements).

Amount of change

The change that has to occur in order to trigger a measurement. If there is insufficient change, measurements will continue at the Minimum rate.

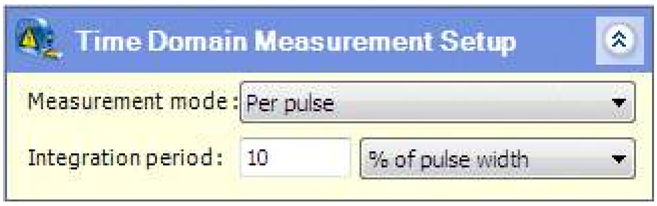
Cycle selection

These check boxes only appear for cyclic *steps* such as triangular sweep, and they are used to select the cycles in which measurements are to be taken.

☞ Cycle Selection, in Measurement Mode: Periodic.

- **Measurement mode: Per pulse**

The Time Domain Measurement Setup sub-screen for this Measurement mode is as follows:



In this case, measurements are taken when each pulse occurs, and if the pulses occur on a changing baseline, an additional measurement will be taken at each interval between pulses.

There is just one field in this sub-screen (in addition to the Measurement mode).

Integration period

The integration period for noise reduction purposes. The value must not exceed the Pulse width defined in the Scan Setup.

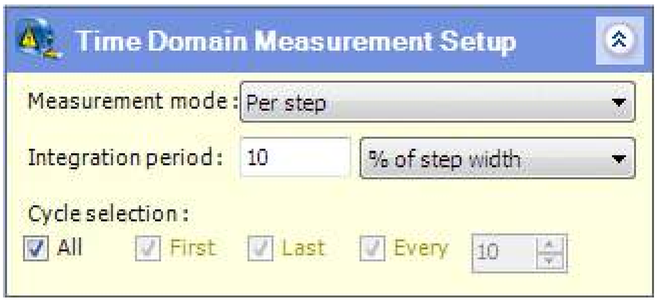
In addition to the units available for Periodic measurements, this field can be specified in the following units:

% of pulse width

☞ Integration period for Measurement mode: Periodic.

- **Measurement mode: Per step**

The Time Domain Measurement Setup sub-screen for this Measurement mode is as follows:



In this case, measurements are taken at the beginning and end of each step.

The fields for this Measurement mode are as follows:

Integration period

The integration period for noise reduction purposes. The value must not exceed the step width, calculated from the Scan rate and Step, specified in the Scan Setup.

In addition to the units available for Periodic measurements, this field can be specified in the following units:

% of step width

☞ Integration period for Measurement mode: Periodic.

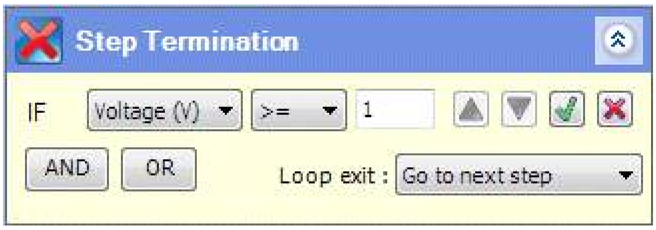
Cycle selection

These check boxes only appear for cyclic *steps* such as triangular sweep, and they are used to select the cycles in which measurements are to be taken.

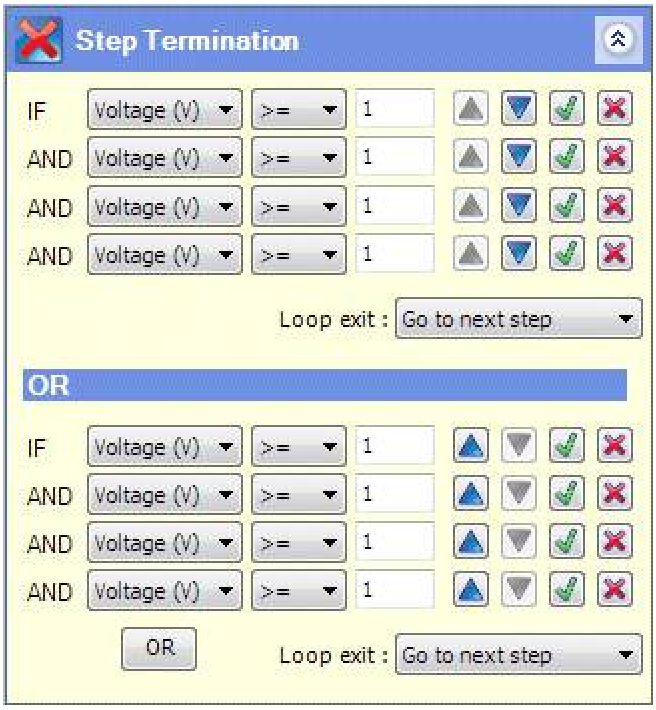
☞ Cycle selection for Measurement mode: Periodic.

5.7.3 Step Termination

This sub-screen in the Step Setup screen specifies the conditions under which the *step* is terminated, using a variety of tests that involve limiting values. The default sub-screen contains a single test as follows:



Multiple tests can be performed using the AND / OR buttons so that successive IF / AND tests can be placed within OR groups as follows:



There can be a maximum of four IF / AND tests within an OR group, and a maximum of four OR groups. The tests and groups are added using the following buttons:

AND

This button adds a new AND test to the current OR group, up to a maximum of four tests including the initial IF test. The button disappears when there are four tests in the group.

OR

This button adds a new OR group containing a single IF test to which more AND tests can be added. There can be a maximum of four OR groups. The button disappears from a group when a new group is added, and does not appear at all in the fourth group.

The fields associated with the tests and results are:

IF / AND (Test)

A test is performed on the excitation signal to the sample, giving a result that is true or false.

The test is set up using three fields as follows:

(variable)

The variable to be tested is selected from a list box as follows:

Voltage (V)
Current (A)
Time (s)
Charge (C)
dV/dt (V/s)
dI/dt (A/s)

(operator)

The operator to be used in the test is selected from the list box as follows:

>=
<=

(value)

The numeric value to which the variable is compared.

The following buttons are available alongside the test:

 Click this button to move the test up to the previous OR group, if there is one.

 Click this button to move the test down to the next OR group, if there is one.

 This button toggles between active (green) and inactive (grey), and the test is only performed when the button is active. When a numeric value is specified for the test, and the cursor is moved to another field, the button automatically becomes active. When the numeric value is deleted, and the cursor is moved to another field, the button automatically becomes inactive. The default screen has a single test with a grey button.

 Click this button to delete the test.

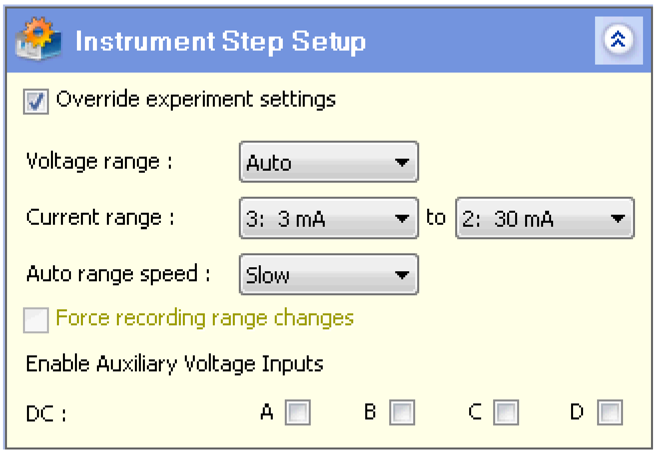
Loop exit

If the *step* is within a *loop*, this list box specifies how the *step* will terminate if the test is true. The options are:

Go to next step	Stay within the *loop* and go to the next *step*. This is the default option.
Exit from loop	Jump out of the *loop* and go to the next *loop* if there is one, or the next *step* in the *experiment*.

5.7.4 Instrument Step Setup

This sub-screen in the Step Setup screen defines the Instrument Step Setup, taking priority over the more general Instrument Experiment Setup.



Instrument Experiment Setup, Section 5.3.4.

The fields are:

Override experiment settings

If this box is checked, the values in this screen are applied to the *step*, and override the Instrument Experiment Setup. If the box is not checked, all the fields are greyed out.

Voltage range

The voltage range of the core module. This field is the same as in the Instrument Experiment Setup.

Current range

The current range of the core module. This field is the same as in the Instrument Experiment Setup.

Auto range speed

The speed at which current range changes can occur, for example when the measurements pass through zero or the data is noisy. This field is the same as in the Instrument Experiment Setup.

Force recording range changes

If this box is checked, range numbers will be included in the data regardless of their effect on data collection. This field is greyed out and displays the entry from the Instrument Experiment Setup.

Enable Auxiliary Voltage Inputs

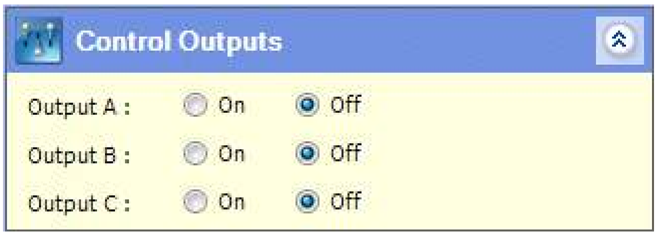
This group of fields determines how the auxiliary channels are to be used in the *experiment*.

DC

The four check boxes, A, B, C, D, indicate the auxiliary channels that are used for DC measurements from accessories, for example temperature probes.

5.7.5 Control Outputs

This sub-screen in the Step Setup screen specifies the control of external devices, for example heaters, stirrers, flow controllers and fans. Control is limited to switching the devices on and off, by closing and opening a circuit, and does not specify how they will operate.



Each core module has three control outputs, A, B and C, and the options for each of them are as follows:

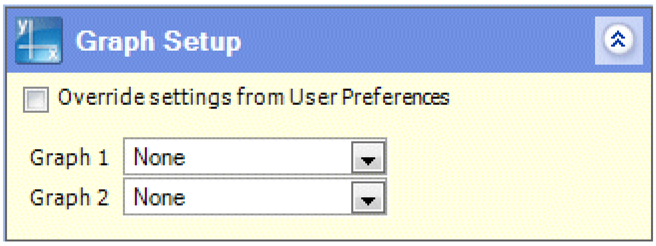
On	The circuit is closed, to turn the device on at the beginning of the *step*, and remains closed throughout the whole *step*.
Off	The circuit is opened, to turn the device off at the beginning of the *step*, and remains open throughout the whole *step*.
	Since the On/Off values apply to the whole *step*, it will be necessary to start a new *step* every time the external device needs to be switched.

The control outputs are available from D-type connectors on the rear panel. On an 8-slot chassis, there are two connectors, representing slots 1-4 and 5-8, and the three control outputs for each slot are available from the appropriate pins. On a 4-slot chassis, there is just a single connector.

☞ Installation Guide, for details of how to connect external devices to the ModuLab XM system.

5.7.6 Graph Setup

This sub-screen in the Step Setup screen specifies the graphical layout of data generated by the *step*.



The fields are:

Override settings from User Preferences

If this box is checked, the values specified in this screen will be used for graphs generated by the *step*. Otherwise, the graphs will conform to the defaults for the *step type*, defined in the Graph Preferences sub-screen in the User Preferences.

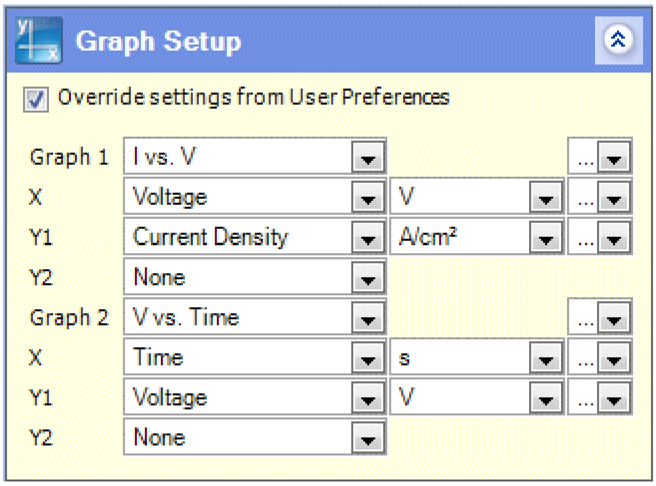
☞ Graph Preferences, Section 4.1.3.

Graph 1, Graph 2

These two fields represent the two graphs that appear in the Data screen when the *experiment* is run and results are obtained.

☞ Data, Section 5.10.

When a selection is made from these fields, a number of other fields appear representing the configuration of the axes as follows:

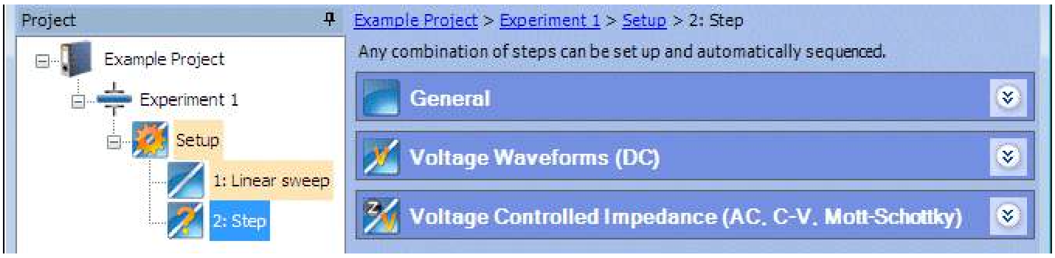


These are described in detail in the Layout of Graphic Displays.

☞ Section 5.11.1.

5.8 STEP TYPES

When you add a *step*, you have to make a selection from a list of *step types*, arranged in categories which are available from a set of collapsed sub-screens as follows:



The sub-screens can be expanded to display the appropriate *step types*, and then when you have completed the addition you can configure the *step*.

☞ Add a New Step, Section 5.6.1

☞ Step Setup, Section 5.7.

The following sub-sections describe the categories of *step types*.

 ☞ General, Section 5.8.1.

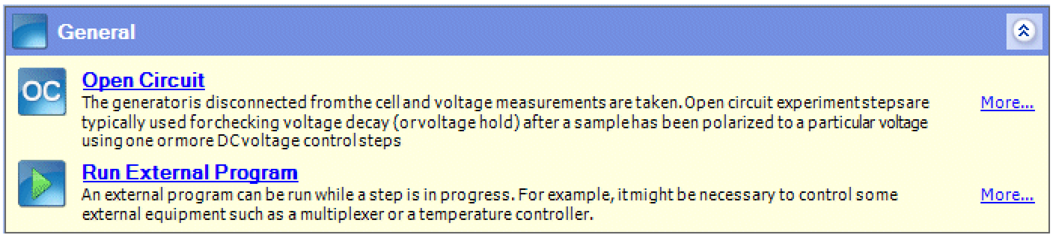
 ☞ Voltage Waveforms (DC), Section 5.8.2.

 ☞ Voltage Controlled Impedance (AC, C-V, Mott-Schottky), Section 5.8.3.

☞ The Scan Setup screens associated with the *step types* are described in Section 5.8.4.

5.8.1 General

The list of *step types* which appears when adding a *step* contains the General category as follows:



☞ Add a New Step, Section 5.6.1

Open Circuit. The generator is disconnected from the sample and voltage measurements are taken. Open circuit *experiments* are typically used for checking voltage decay (or voltage hold) after a sample has been polarized to a particular voltage.

Run External Program. An external program can be run while a *step* is in progress. For example, it might be necessary to run some external equipment such as a multiplexer or temperature controller.

☞ Section 5.8.4.15.

NOTE: The Temperature Settling *step* also belongs to the General category, but it does not appear in the list of *step types* because it cannot be added to an *experiment* Setup in the usual way. Instead it appears automatically in a temperature scanning *loop*.

☞ Temperature Settling Step, Section 5.9.3.1.

5.8.2 Voltage Waveforms (DC)

DC Voltage Waveforms are applied to an *experiment* by stimulating the sample with a signal from the generator.

The *step types* in this category, which appear when adding a *step*, are shown in the following sub-screen:

☞ Add a New Step, Section 5.6.1

In these *step types*, the voltage from the generator follows a specified waveform as follows:

Constant Level. The voltage is held at a constant value for a specified time period.

☞ Section 5.8.4.5.

Linear Sweep I-V Characterisation. There is a linear scan of voltage between two limits.

☞ Section 5.8.4.7.

Triangular Sweep I-V Characterisation. There is a cyclic linear scan of voltage between two limits.

☞ Section 5.8.4.8.

Staircase Linear Sweep. There is a scan of voltage between limits, according to a step function.

☞ Section 5.8.4.9.

Staircase Triangular Sweep. There is a scan of voltage between limits, according to a step function, but the direction is periodically reversed, creating a cyclic waveform.

☞ Section 5.8.4.10.

Pulse. There is a series of pulses of voltage, of constant amplitude.

☞ Section 5.8.4.11.

Sweep Pulse. There is a series of pulses of varying voltage, so that each pulse differs from the previous one by a specified *step*.

☞ Section 5.8.4.12.

Differential Pulse. There is a scan of voltage between limits, according to a step function, but a pulse is added to each step.

☞ Section 5.8.4.13.

Square Wave. There is a scan of voltage between limits, according to a step function, but a square wave is superimposed on each step.

☞ Section 5.8.4.14.

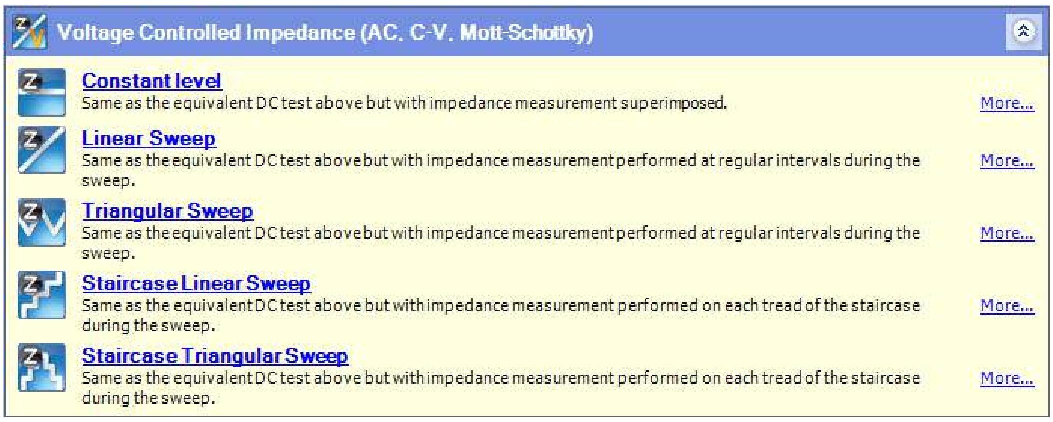
Any combination of the above tests may be used to create arbitrary waveforms that include sweeps, steps, constant levels and pulses.

5.8.3 Voltage Controlled Impedance (AC, C-V, Mott-Schottky)

Voltage Controlled Impedance is applied to an *experiment* by adding an alternating voltage to a sample that is already stimulated with DC voltage waveforms, and applying a range of frequencies. An FRA is required to supply the alternating voltage, and the frequency range is defined in the Impedance Setup sub-screen.

☞ Impedance Setup, Section 5.7.1.

The *step types* in this category, which appear when adding a *step*, are shown in the following sub-screen:



☞ Add a New Step, Section 5.6.1

In these *step types*, the voltage from the generator follows a specified DC waveform, and an alternating voltage is superimposed on it to provide impedance measurements. The *step types* are as follows:

Constant Level Impedance. The DC voltage is held at a constant value.

☞ Section 5.8.4.6.

Linear Sweep Impedance. The DC voltage follows a linear variation between two limits.

☞ Section 5.8.4.7.

Triangular Sweep Impedance. The DC voltage follows a cyclic linear scan between two limits.

☞ Section 5.8.4.8.

Staircase Linear Sweep Impedance. The DC voltage follows a step function.

☞ Section 5.8.4.9.

Staircase Triangular Sweep Impedance. The DC voltage follows a step function which periodically reverses.

☞ Section 5.8.4.10.

NOTE: The complete step names, including the word “Impedance” are in the left-hand navigation panel.

5.8.4 Scan Setup

When you configure a *step*, as described in the Step Setup, you have to fill in a set of sub-screens which may vary according to the *step type*.

☞ Step Setup, Section 5.7.

The Scan Setup sub-screen defines the output signal to the sample, and varies according to the shape of the waveform (linear sweep, triangular, staircase, etc.) The following sub-sections describe general considerations that apply to all output signals to the sample:

☞ Relative Values, Section 5.8.4.1. This specifies how a voltage is defined as the difference between two values.

☞ Units, Section 5.8.4.2. These may have to be specified for duration, level, scan rate and frequency.

☞ Voltage Compensation for Output Impedance, Section 5.8.4.3. The voltage output to the sample has to take into account the impedance of the module.

The following sub-sections describe all the variations of the Scan Setup sub-screen:

☞ Open Circuit, Section 5.8.4.4.

☞ Constant Level DC Measurement, Section 5.8.4.5.

☞ Constant Level Impedance, Section 5.8.4.6.

☞ Linear Sweep, Section 5.8.4.7.

☞ Triangular Sweep, Section 5.8.4.8.

☞ Staircase Linear Sweep, Section 5.8.4.9.

☞ Staircase Triangular Sweep, Section 5.8.4.10.

☞ Pulse, Section 5.8.4.11.

☞ Sweep Pulse, Section 5.8.4.12.

☞ Differential Pulse, Section 5.8.4.13.

☞ Square Wave, Section 5.8.4.14.

☞ Temperature Settle, within Temperature Loop, Section 5.9.3.1.

5.8.4.1 Relative Values

Voltage is always defined as a difference between two values, although it is normally only necessary to specify one value against an arbitrary base value, for example ground.

Most of the Scan Setup sub-screens have fields where a voltage has to be specified, and an additional list box is available in case a specific base value is required. For example, in the screen for Constant Level Impedance, a DC voltage level can be specified relative to the end of the previous *step* is as follows:

Alongside the value and units fields, there is a list box with the following options:

vs. Open Circuit — The value is specified relative to the open circuit voltage of the sample, measured at the end of the last open circuit *step*. For example, if a sample generates 1.5V in open circuit, and you specify a voltage of 1V, the overall voltage will be 2.5V.

When this option is selected, it is recommended that the previous *step* should be open circuit, because open circuit potential is only measured during an open circuit *step*, and at the beginning of the *experiment*.

Absolute — The value is specified in absolute terms without reference to any other values.

vs. Previous — The value is specified relative to the voltage measured at the end of the previous *step*.

DC Scan Value — Only applicable to *steps* within DC bias scanning loops.

☞ DC Bias Scanning Loop, Section 5.9.2 and Scan Setup for DC Bias Scanning Loop, Section 5.9.2.1.

This list box does not appear in fields where a change of voltage is being specified, for example a pulse or step.

5.8.4.2 Units

The same units are generally available for similar fields that occur repeatedly throughout the Scan Setup sub-screens as follows:

Duration

µs
ms
s
Minute
Hour
Day

Level

µV
mV
V

Scan rate

µV/s
mV/s

V/s
kV/s
MV/s

Frequency

µHz
mHz
Hz
kHz
MHz
ω

5.8.4.3 Voltage Compensation for Output Impedance

The voltage output from a module is applied across two impedances:

- The impedance of the sample.
- The impedance of the module that supplies the generator output to the sample. These are:

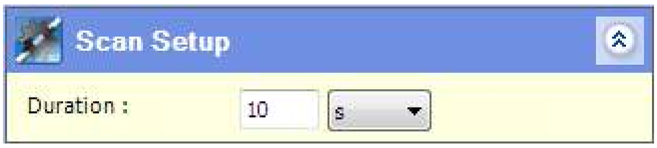
Module	Output Impedance
Materials Core Module	50Ω
High Voltage Module	50Ω
2A Booster	<1Ω
Femto Ammeter	Not applicable, used for measurement only. Generator signal to sample is applied from core module, HV module or booster.
Sample and Reference Module	Not applicable, uses generator output from core module or HV module.

In cases where the output impedance of the module constitutes a significant proportion of the total impedance, the voltage levels specified in the Scan Setup screen have to be increased to account for it, but the measured results are based on the voltage that is actually applied to the sample.

For example, if a 2A booster with 0.4Ω output impedance is connected to a sample with 0.1Ω resistance (as in the ModuLab XM MTS 0.1Ω Test Unit), and a voltage level of 800mV is specified in the Scan Setup screen, the voltage will be split between 640mV for the module and 120mV for the sample. However, the measurements will be based on the voltage applied to the sample, so that a value of 120mV will appear in the results.

5.8.4.4 Open Circuit

For open circuit *experiments*, the Scan Setup sub-screen which appears in the Step Setup is as follows:



☞ Step Setup, Section 5.7.

The following *step type* uses this sub-screen:

Step Type	Category
Open Circuit	General

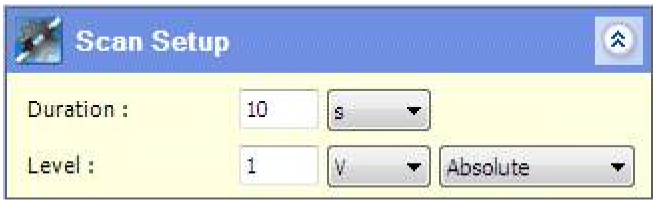
There is a single field as follows:

Duration

The time period for the scan.

5.8.4.5 Constant Level DC Measurement

In this *step type*, the sample is maintained at a constant voltage for a specified time period. The Scan Setup sub-screen which appears in the Step Setup is as follows:



☞ Step Setup, Section 5.7.

The following *step type* uses this sub-screen:

Step Type	Category
Constant Level	Voltage Waveforms (DC)

The fields are as follows:

Duration

The time period for the scan.

Level

The constant voltage at which the sample is maintained, relative to an appropriate base value.

☞ Relative Values, Section 5.8.4.1.

5.8.4.6 Constant Level Impedance

In this *step type*, the sample is maintained at a constant DC voltage and a frequency is applied. The Scan Setup sub-screen which appears in the Step Setup is as follows:

☞ Step Setup, Section 5.7.

The following *step type* uses this sub-screen:

Step Type	Category
Constant Level Impedance	Voltage Controlled Impedance

There is a single field are as follows:

DC Level

The constant level at which the sample is maintained, relative to an appropriate base value.

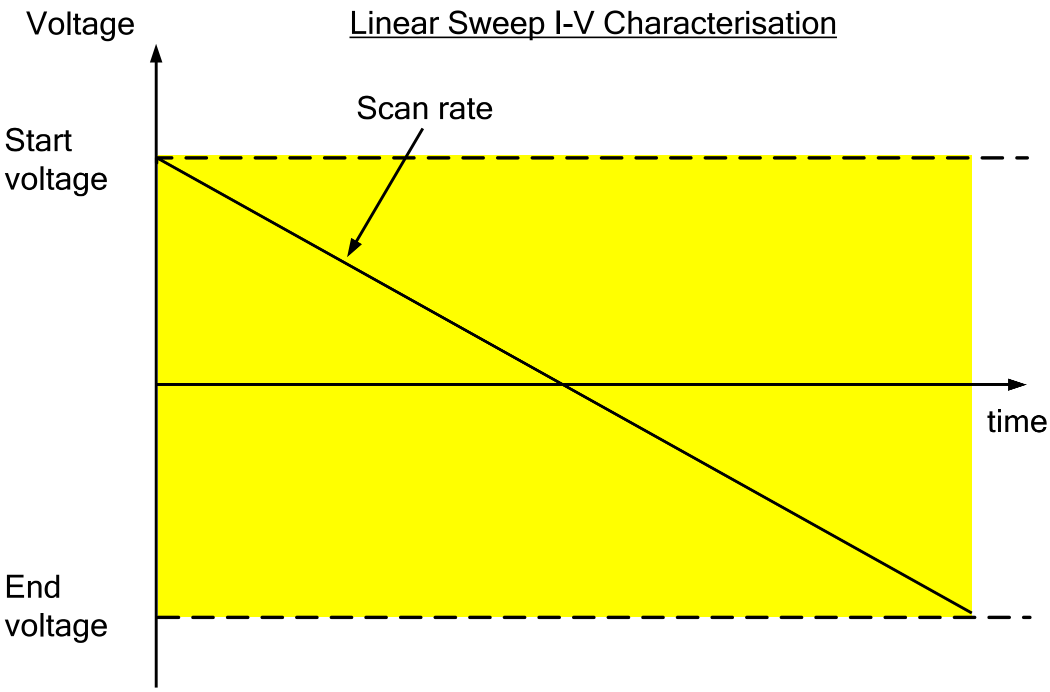
☞ Relative Values, Section 5.8.4.1.

NOTE: A duration is not specified because it is defined by the Impedance Setup. The scan terminates at the end of the sweep, or at the end of the integration time in the case of a Single Frequency *step*.

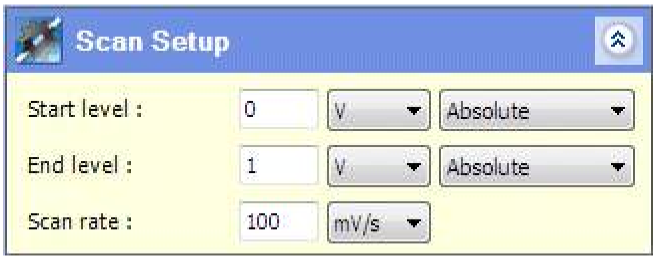
☞ Impedance Setup, Section 5.7.1.

5.8.4.7 Linear Sweep

In this *step type*, the sample follows a waveform with a linear variation of voltage between two limits.



The corresponding Scan Setup sub-screen which appears in the Step Setup is as follows:



☞ Step Setup, Section 5.7.

The following *step types* use this sub-screen:

Step Type	**Category**
Linear Sweep I-V Characterisation	Voltage Waveforms (DC)
Linear Sweep Impedance	Voltage Controlled Impedance

The voltage levels are specified relative to an appropriate base value.

☞ Relative Values, Section 5.8.4.1.

The fields are:

Start level

The voltage level at which the scan begins.

End level

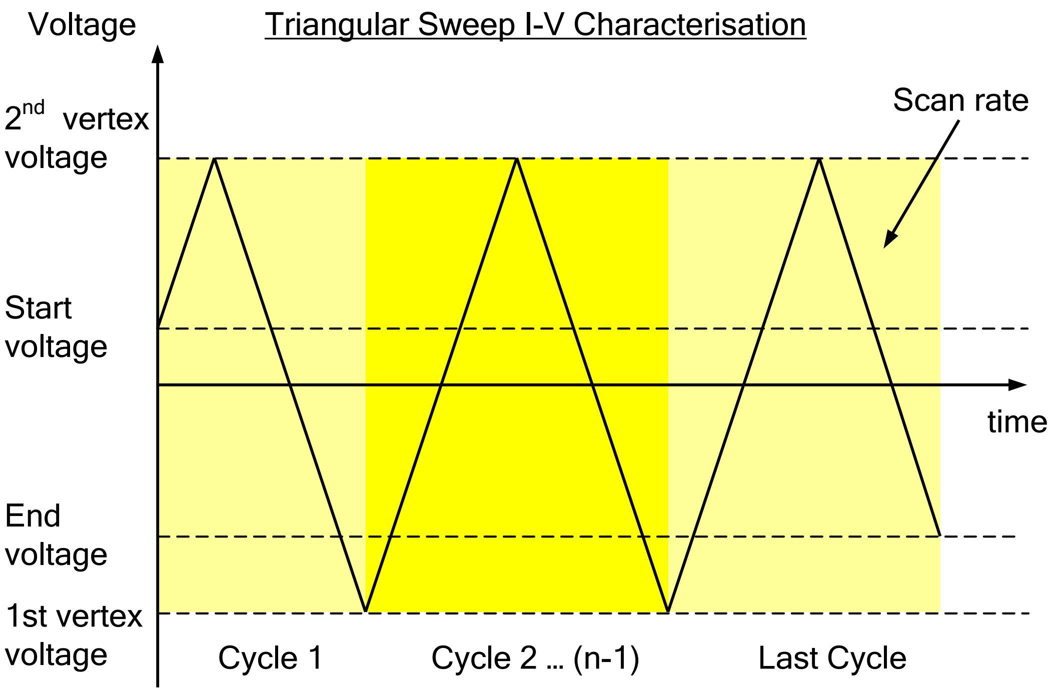
The voltage level at which the scan ends.

Scan rate

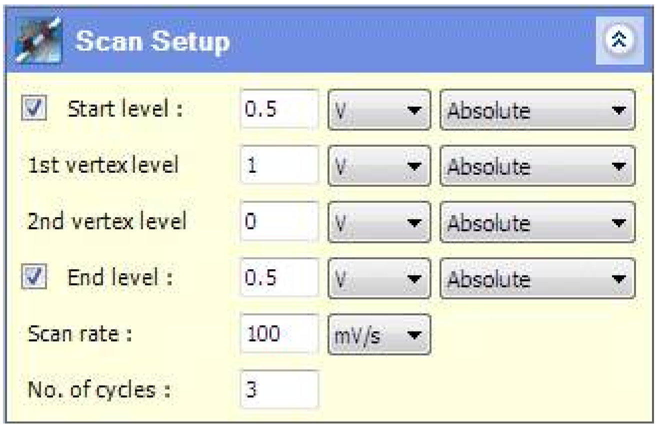
The constant rate of change of voltage, between the start and end voltage.

5.8.4.8 Triangular Sweep

In this *step type*, the sample follows a waveform with a cyclic linear scan of voltage between two limits as follows:



The corresponding Scan Setup sub-screen which appears in the Step Setup is as follows:



☞ Step Setup, Section 5.7.

The following *step types* use this sub-screen:

Step Type	Category
Triangular Sweep I-V Characterisation	Voltage Waveforms (DC)
Triangular Sweep Impedance	Voltage Controlled Impedance

The voltage levels are specified relative to an appropriate base value.

☞ Relative Values, Section 5.8.4.1.

The fields are:

Start level

This field consists of a check box and a numeric value. If the box is checked, the field specifies the voltage level at which the scan begins during the first half of a cycle before it reverses direction.

If the box is not checked, the scan begins at the 1st vertex level.

The check box affects the 1st and 2nd vertex level fields as follows:

- If the box is checked, the 1st vertex level represents the mid-point of a cycle where the scan direction is reversed, and the 2nd vertex level will be at the start and end point of each cycle.
- If the box is not checked, the 1st vertex level represents the start and end point of each cycle, and the 2nd vertex level represents the mid-point of a cycle where the scan direction is reversed.

The specified start level should not be outside the range of the 1st and 2nd vertex levels.

1st / 2nd vertex levels

These two fields specify the voltage levels at the vertices of the triangular sweep. One field represents the start and end point of each cycle, while the other field represents the mid-point of a cycle, depending on whether or not the Start Level box has been checked.

End level

This field consists of a check box and a numeric value. If the box is checked, the field specifies the voltage level at which the scan ends during the second half of the last cycle, after it has reversed direction.

If the box is not checked, the scan ends on completion of the last cycle.

The specified end level should not be outside the range of the 1st and 2nd vertex levels.

Scan rate

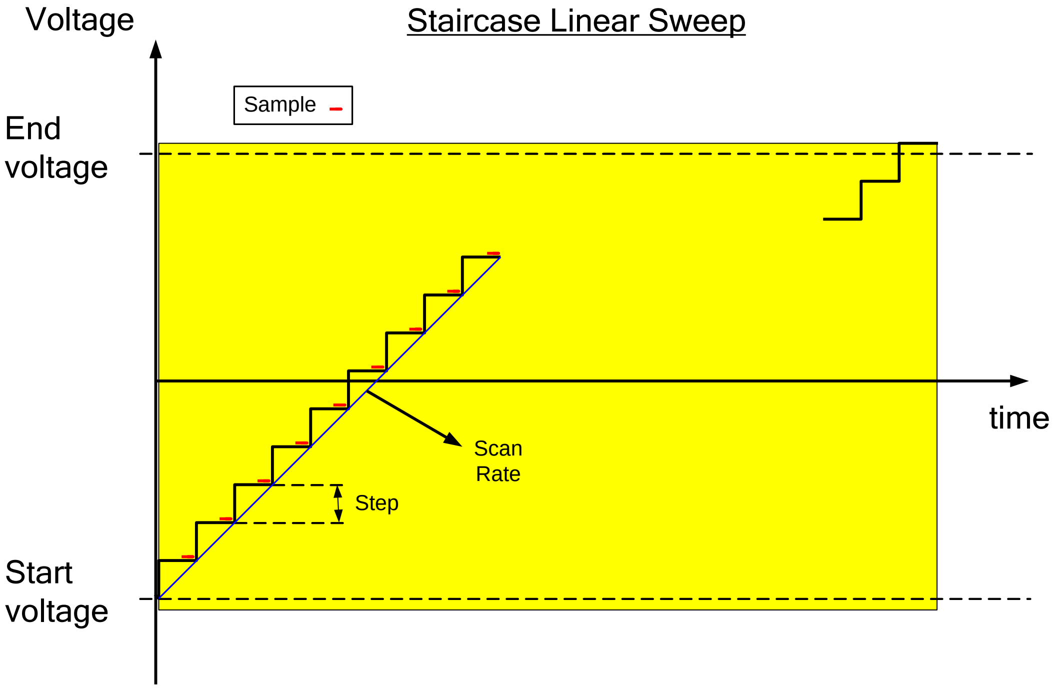
The constant absolute rate of change of voltage as it rises and falls between the two vertices. The scan may start in the direction of increasing or decreasing voltage, depending on how the start level and vertex fields have been set.

No. of cycles

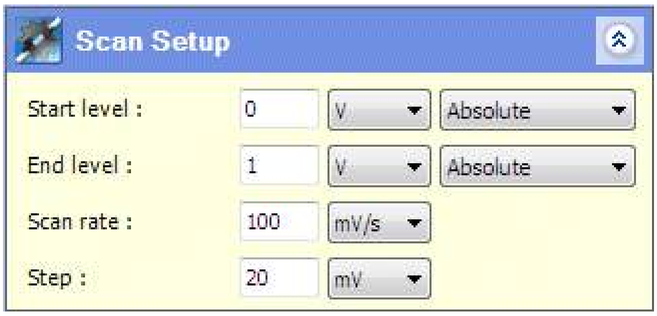
The number of cycles to be fully or partially completed.

5.8.4.9 Staircase Linear Sweep

In this *step type*, the sample follows a waveform with a voltage that varies according to a linear step function.



The corresponding Scan Setup sub-screen which appears in the Step Setup is as follows:



☞ Step Setup, Section 5.7.

The following *step types* use this sub-screen:

Step Type	Category
Staircase Linear Sweep	Voltage Waveforms (DC)
Staircase Linear Sweep Impedance	Voltage Controlled Impedance

Voltages in this sub-screen are specified relative to an appropriate base value.

☞ Relative Values, Section 5.8.4.1.

The fields are:

Start level

The voltage at which the scan begins.

End level

The voltage at which the scan ends.

Scan rate

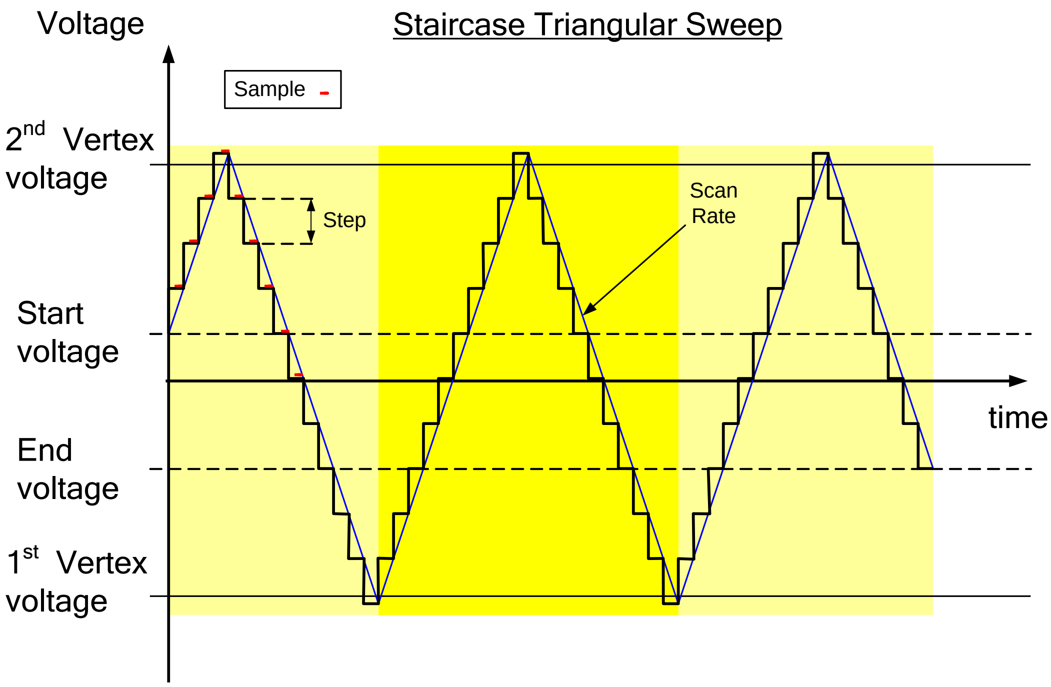
The constant rate of change of voltage, between the start and end level, defining the linear scan on which the staircase is superimposed.

Step

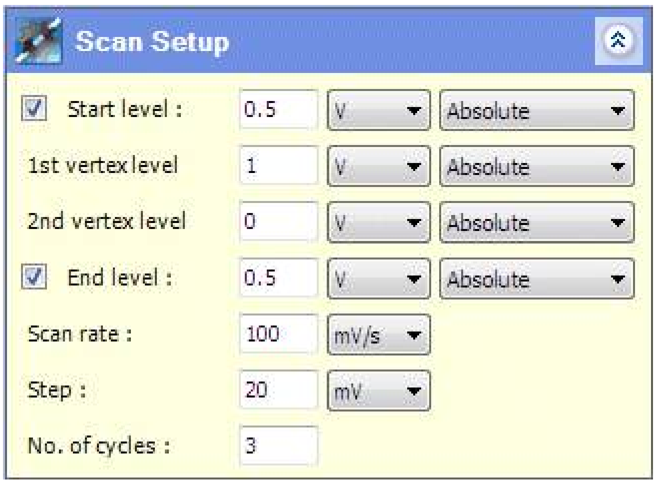
The voltage level of each step that is superimposed on the linear scan.

5.8.4.10 Staircase Triangular Sweep

In this *step type*, the sample follows a waveform with a voltage that varies according to a cyclic step function.



The corresponding Scan Setup sub-screen which appears in the Step Setup is as follows:



☞ Step Setup, Section 5.7.

The following *step types* use this sub-screen:

Step Type	Category
Staircase Triangular Sweep	Voltage Waveforms (DC)
Staircase Triangular Sweep Impedance	Voltage Controlled Impedance

Voltages in this sub-screen are specified relative to an appropriate base value.

☞ Relative Values, Section 5.8.4.1.

The fields are:

Start level

This field consists of a check box and a numeric value. If the box is checked, the field specifies the voltage level at which the scan begins during the first half of a cycle before it reverses direction.

If the box is not checked, the scan begins at the 1st vertex level.

The check box affects the 1st and 2nd vertex level fields as follows:

- If the box is checked, the 1st vertex level represents the mid-point of a cycle where the scan direction is reversed, and the 2nd vertex level will be at the start and end point of each cycle.
- If the box is not checked, the 1st vertex level represents the start and end point of each cycle, and the 2nd vertex level represents the mid-point of a cycle where the scan direction is reversed.

The specified start level should not be outside the range of the 1st and 2nd vertex levels.

1st / 2nd vertex levels

These two fields specify the voltage levels at the vertices of the triangular sweep. One field represents the start and end point of each cycle, while the other field represents the mid-point of a cycle, depending on whether or not the Start Level box has been checked.

End level

This field consists of a check box and a numeric value. If the box is checked, the field specifies the voltage level at which the scan ends during the second half of the last cycle, after it has reversed direction.

If the box is not checked, the scan ends on completion of the last cycle.

The specified end level should not be outside the range of the 1st and 2nd vertex levels.

Scan rate

The constant absolute rate of change of voltage as it rises and falls between the two vertices. The scan may start in the direction of increasing or decreasing voltage, depending on how the start level and vertex fields have been set.

Step

The voltage of each step that is added to the rising scan, or subtracted from the falling scan.

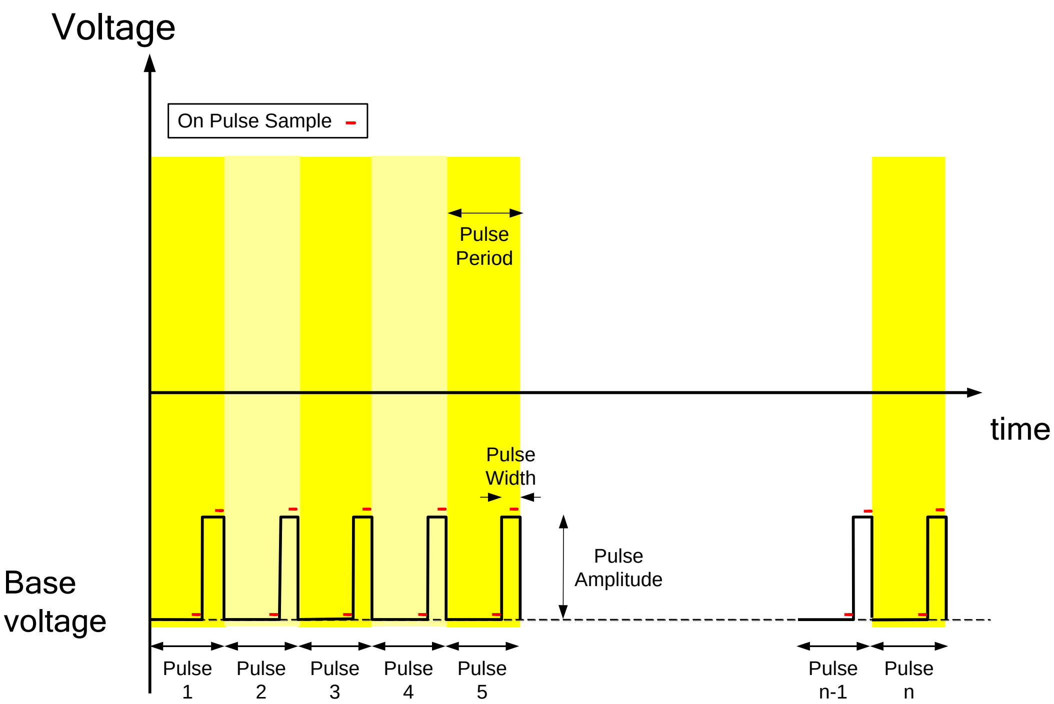
No. of cycles

The number of cycles to be fully or partially completed.

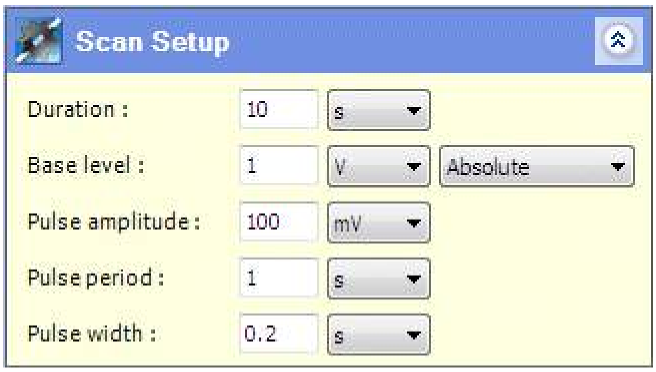
5.8.4.11 Pulse

In this *step type*, the sample is stimulated with a series of voltage pulses of constant amplitude above a base level.

Pulse



The corresponding Scan Setup sub-screen which appears in the Step Setup is as follows:



☞ Step Setup, Section 5.7.

The following *step type* uses this sub-screen:

Step Type	Category
Pulse	Voltage Waveforms (DC)

The fields are:

Duration

The duration of the scan, until it terminates.

Base level

The voltage between pulses, specified relative to an appropriate base value.

☞ Relative Values, Section 5.8.4.1.

Pulse amplitude

The voltage level of each pulse, relative to the Base Level.

Pulse period

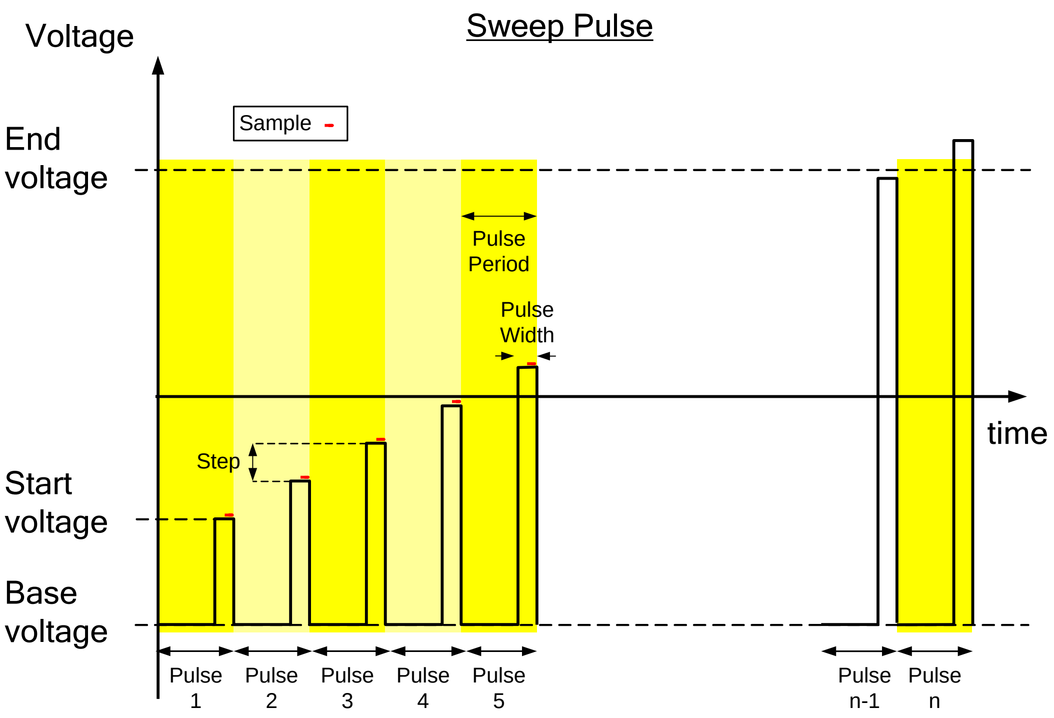
The time period between successive pulses. This is made up of the interval between pulses followed by the pulse width.

Pulse width

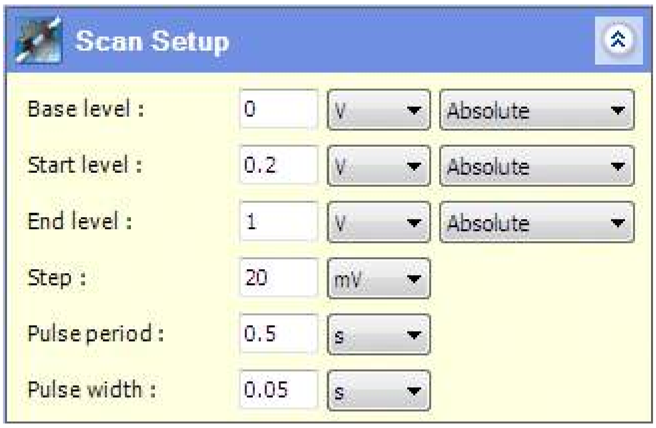
The duration of each pulse, excluding the interval between pulses.

5.8.4.12 Sweep Pulse

In this *step type*, the sample follows a waveform with a series of pulses of varying voltage, so that each pulse differs from the previous one by a specified step.



The corresponding Scan Setup sub-screen which appears in the Step Setup is as follows:



☞ Step Setup, Section 5.7.

The following *step type* uses this sub-screen:

Step Type	Category
Sweep Pulse	Voltage Waveforms (DC)

Voltages in this sub-screen are specified relative to an appropriate base value.

☞ Relative Values, Section 5.8.4.1.

The fields are:

Base level

The voltage during the interval between pulses.

Start level

The voltage of the first pulse.

End level

The terminating voltage, so that the scan ends after a pulse has exceeded this value.

Step

The voltage of each successive pulse, relative to the previous pulse.

Pulse period

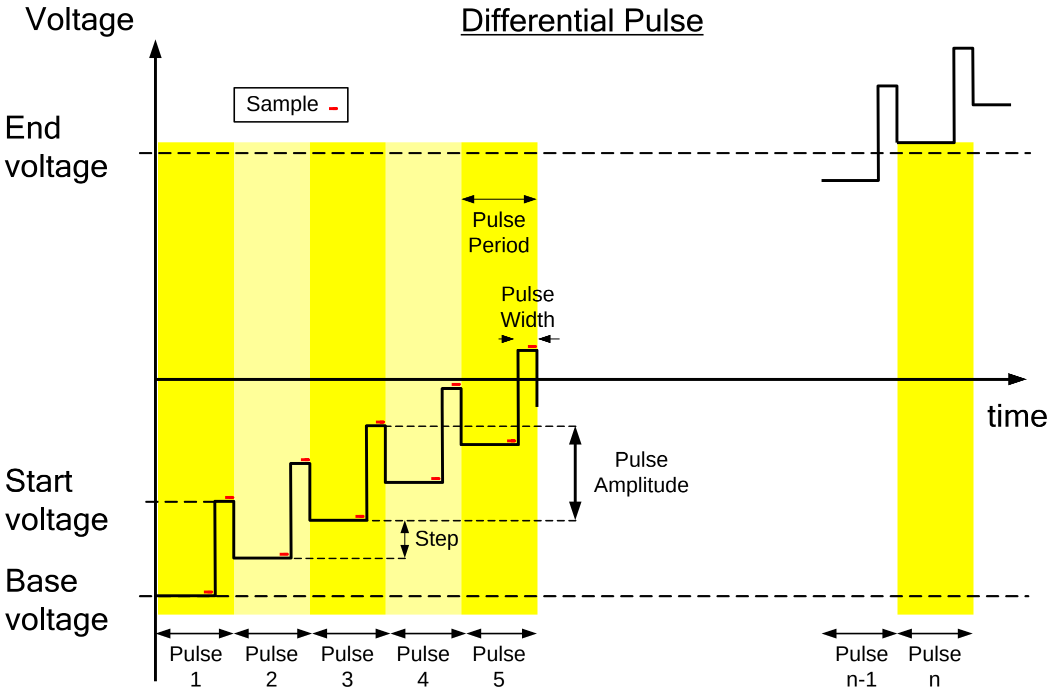
The time period between successive pulses. This is made up of the interval between pulses (when the voltage is at the base value), followed by the pulse width.

Pulse width

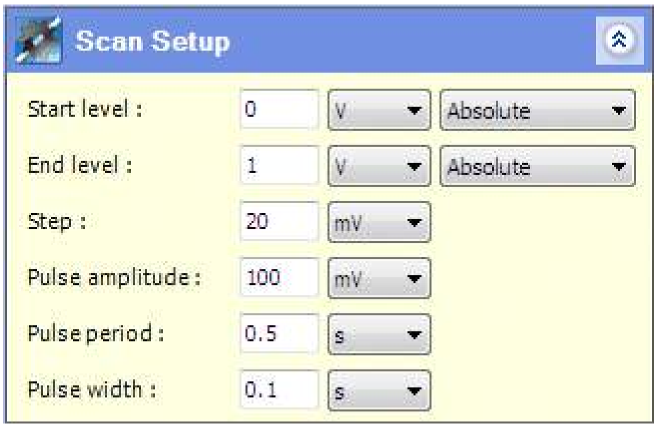
The duration of each pulse, excluding the interval between pulses.

5.8.4.13 Differential Pulse

In this *step type*, the sample follows a waveform with a voltage that varies according to a step function, but a pulse is added at the entry to each step.



The corresponding Scan Setup sub-screen which appears in the Step Setup is as follows:



☞ Step Setup, Section 5.7.

The following *step type* uses this sub-screen:

Step Type	Category
Differential Pulse	Voltage Waveforms (DC)

Voltages in this sub-screen are specified relative to an appropriate base value.

☞ Relative Values, Section 5.8.4.1.

The fields are:

Start level

The voltage that precedes the first pulse, before any *steps* have been added.

End level

The terminating voltage, so that the scan ends after a pulse has occurred, beginning with a voltage that exceeds this value.

Step

The change in voltage at the entry to each successive pulse, relative to the previous pulse.

Pulse amplitude

The voltage of each pulse, as it rises above the level at the entry to the pulse.

Pulse period

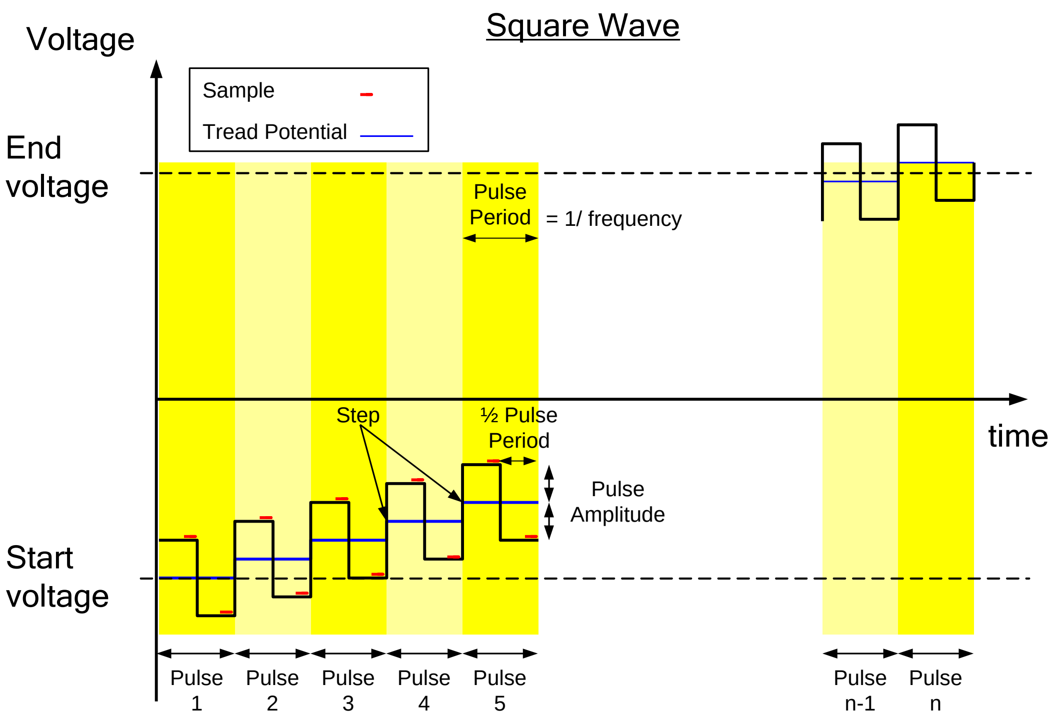
The time period between successive pulses. This is made up of the interval between pulses (when the voltage is at the entry level), followed by the pulse width.

Pulse width

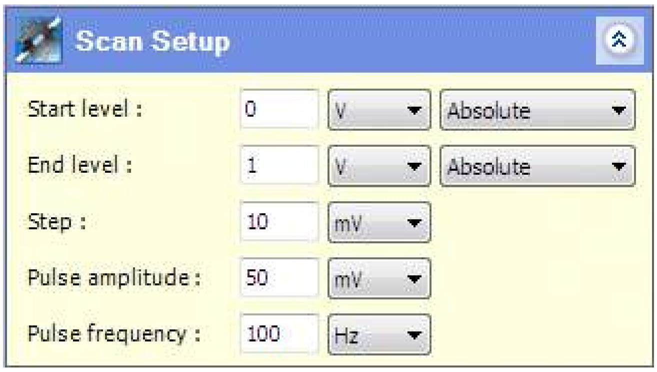
The duration of each pulse, excluding the interval between pulses.

5.8.4.14 Square Wave

In this *step type*, the sample follows a waveform with a voltage that varies according to a step function, but a square wave is superimposed on each step.



The corresponding Scan Setup sub-screen which appears in the Step Setup is as follows:



☞ Step Setup, Section 5.7.

The following *step type* uses this sub-screen:

Step Type	Category
Square Wave	Voltage Waveforms (DC)

Voltages in this sub-screen are specified relative to an appropriate base value.

☞ Relative Values, Section 5.8.4.1.

The fields are:

Start level

The starting voltage of the step function, before the squarewave has been added.

End level

The terminating voltage, so that the scan ends after a squarewave has occurred on a step that exceeds this value.

Step

The voltage of each successive step, relative to the previous one.

Pulse amplitude

The amplitude of the squarewave, above and below the step.

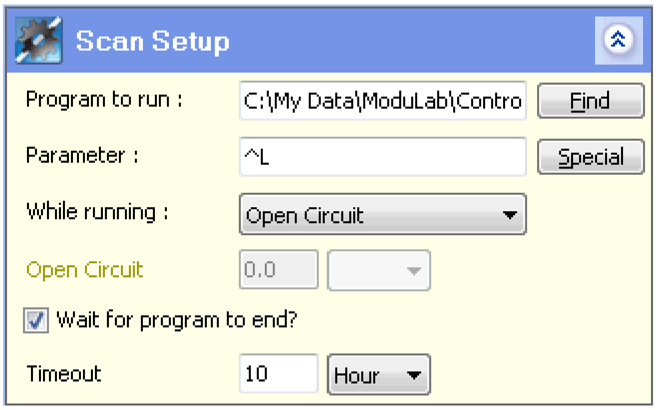
Pulse Frequency

The frequency of the squarewave, consisting of the upper and lower sections, superimposed on its corresponding step.

5.8.4.15 Run External Program

This *step type* runs an external program, for example to control a multiplexer so that a single *instrument group* can take sequential measurements from multiple samples.

This *step type* is available in the General category in the Scan Setup sub-screen which appears in the Step Setup is as follows:



☞ Step Setup, Section 5.7.

The fields are:

Program to run

The full pathname of the program to be run (or the file to be opened, causing a program to run), while this *step* is running.

Find

Use this button to navigate the filing system to find the program or file.

Parameter

Any command line parameters that need to be appended to the program or filename.

Special

This button adds the following characters to the Parameter field, which have a special meaning in ModuLab XM:

^L	Loop iteration. If the *step* is within a *loop*, this represents the iteration number (1, 2, etc.)
^S	Step ID. This represents the *step* number, when this *step* is placed alongside other *steps* at the same level. If the *step* is within a *loop*, or a set of nested *loops*, the Step ID will consist of a pair of numbers for each level of looping, followed by the *step* number at the bottom level. For example, 1.2.3.4.5 means the second time round the first *step* (which is a *loop*) at the top level, and the fourth time round the third *step* (which is a *loop*) at the next level, and this *step* is fifth in the *loop*.
^^	This represents a single ^ character, in case it is needed as a normal command line parameter.

While running

This represents the signal to be applied to the sample while the *step* is running. The options are:

Open circuit
Constant Voltage

☞ Sections 5.8.4.4 and 5.8.4.5.

Open Circuit / Voltage

This field has the appropriate title, depending on the selection from the previous field, and represents the signal level as follows:

Open circuit	The field is greyed out because no signal is applied.
Voltage	Specify a voltage signal in the appropriate units, relative to an appropriate base value. ☞ Relative Values, Section 5.8.4.1.

Wait for program to end?

If this box is checked, the *step* continues running until the program has ended or the Timeout has been reached. If the *step* has to terminate because the Step Termination conditions have been reached, the program will stop.

☞ Step Termination, Section 5.7.3.

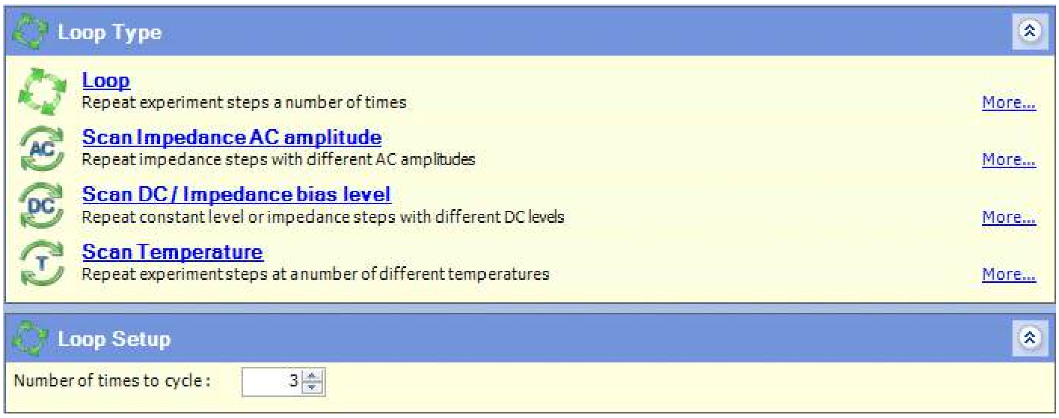
If the box is not checked, the *step* terminates when the program starts. It takes about one second to detect that the program has started.

Timeout

If the Wait for program to end box has been checked, this field specifies the maximum amount of time that the *step* continues running while waiting for the program to end.

5.9 LOOP TYPES

When a *loop* is selected from the left-hand navigation panel, a selection of Loop Types and their corresponding Loop Setup sub-screens appears as follows:



The Loop Types are as follows:

Loop

This is the standard *loop* where the corresponding Loop Setup contains a single field:

Number of times to cycle

When the *experiment* is run, it will cycle round the *loop* the specified number of times, implementing all the *steps* and sub-*loops* each time round the cycle.

Scan Impedance AC Amplitude

The *loop* contains a list of AC voltage amplitude levels and performs a cycle for each entry in the list. Each impedance *step* within the *loop* may optionally use the amplitude from the *loop*, or its own amplitude defined within the *step*.

☞ Sections 5.9.1 and 5.9.1.1.

Scan DC / Impedance Bias Level

The *loop* contains a list of DC bias levels and performs a cycle for each entry in the list. Each constant level DC or impedance *step* within the *loop* may optionally use the DC bias from the *loop*, or its own bias defined within the *step*.

☞ Sections 5.9.2 and 5.9.2.1.

Scan Temperature

The *loop* contains a list of temperatures and performs a cycle for each entry in the list. Each cycle begins with a temperature settling *step* followed by any additional *steps* with the sample at the required temperature.

☞ Sections 5.9.3 and 5.9.3.1.

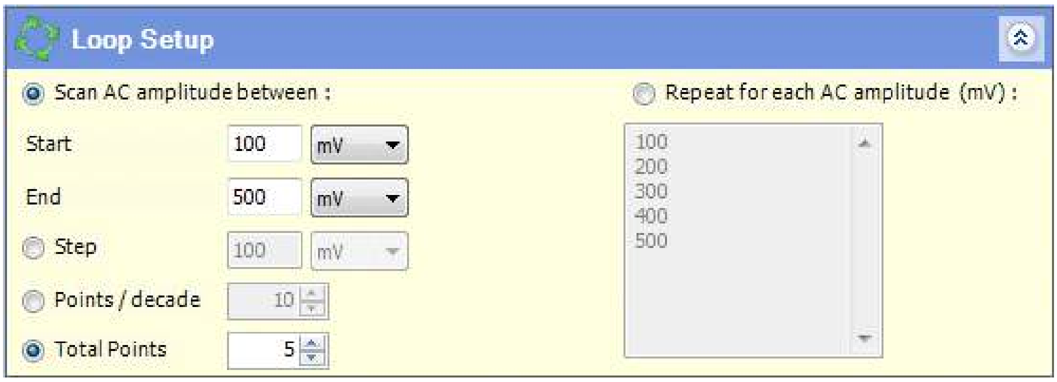
NOTE: All *loop types*, including scanning *loops*, can be nested at multiple levels. In the case of scanning *loops*, the *steps* underneath them will take values from the nearest appropriate parent. If a temperature *loop* is included, it should normally be the outer *loop* so that the sample can reach the specified temperature.

5.9.1 AC Amplitude Scanning Loop

When a *loop* is selected from the left-hand navigation panel, and Scan Impedance AC Amplitude is selected from the Loop Type sub-screen, the *loop* can be configured to perform one cycle for each entry in a list of AC amplitude voltage levels. The specified amplitude is applied to each impedance *step* within the *loop*, but only if AC scan value has been selected from the Impedance Setup.

☞ Impedance Setup for AC Amplitude Scanning Loop, Section 5.9.1.1.

The Loop Setup sub-screen for this *loop type* is as follows:



The fields at the left of this sub-screen are used to generate the list of AC amplitudes at the right, which can then be directly edited, in case specific values are required. The fields are:

Scan AC amplitude between

If this radio button is selected, the interval between two AC voltage amplitudes is divided into a series of values. The fields under this button are:

Start

The AC amplitude to be applied on the first cycle round the *loop*.

End

The AC amplitude to be applied during the last cycle round the *loop*.

Step

The change of AC amplitude between successive cycles, until the End value is reached.

If this radio button is selected, the Points / decade and Total Points fields will be greyed out but will display appropriate values. If a value is specified in this field, the Total Points field will be recalculated, giving the points required between the Start and End values.

Points / decade

The number of values to be applied at logarithmic intervals during each decade of AC amplitude change.

If this radio button is selected, the Step and Total Points fields will be greyed out but will display appropriate values. If a value is specified in this field, the Total Points field will be recalculated, giving the points required between the Start and End values.

Total Points

The number of values to be applied between the Start and End values.

If this radio button is selected, the Step and Points / decade fields will be greyed out but will display appropriate values. If a value is specified in this field, the Step field will be recalculated, giving the change of amplitude between successive cycles.

Repeat for each AC amplitude (mV)

This radio button enables the list of AC amplitudes underneath it to be directly edited, in case specific values are required. Otherwise, the list is greyed out and contains the values calculated from the fields on the left**.**

New values can be typed or pasted in, separated by any of the following delimiters:

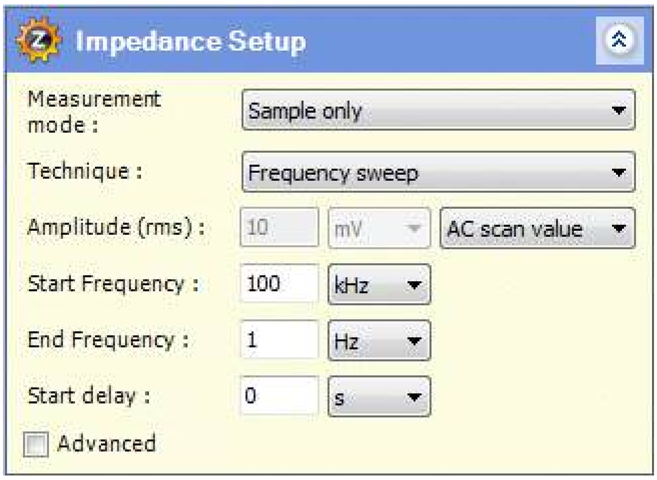
Tab
Space
New line
Semi-colon (;)
Comma (,) unless it is used as the decimal separator character.

When the screen is re-displayed, the delimiters will be converted to line breaks so that each value appears on a new line.

5.9.1.1 Impedance Setup for AC Amplitude Scanning Loop

An impedance *step* under an AC amplitude scanning *loop* can be optionally configured to take its amplitude from the *loop* as follows:

1. Click on the *step*, in the left-hand navigation panel, to display the sub-screens for the *step* configuration.
2. In the Impedance Setup sub-screen, set the Amplitude (rms) field to AC scan value as follows:



The fields for entering the value and units have become greyed out because the *step* takes its amplitude from the *loop*.

NOTE: AC scan value should only be specified for a *step* that is inside an AC amplitude scanning *loop*, otherwise the *experiment* will not run.

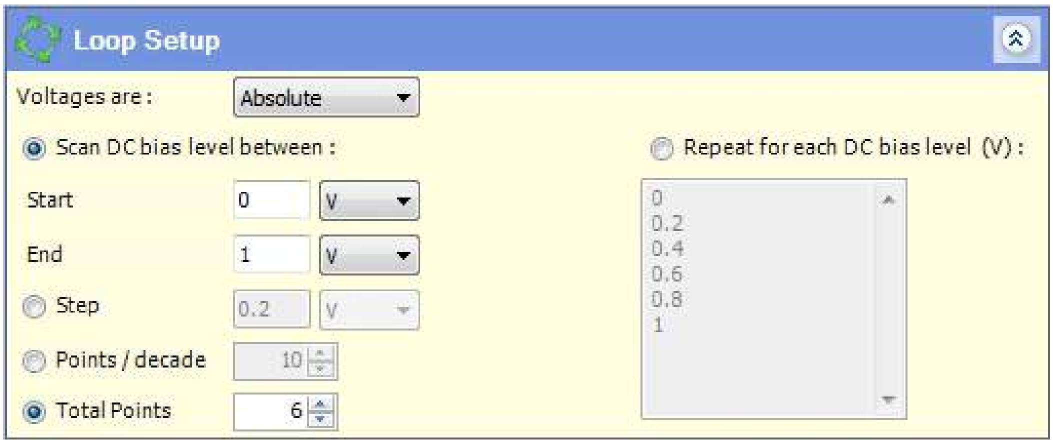
NOTE: Any *step type* may be included in an AC amplitude scanning *loop*, but only impedance *steps* can take values from the *loop*. DC *steps* will use their own specified voltage levels.

5.9.2 DC Bias Scanning Loop

When a *loop* is selected from the left-hand navigation panel, and Scan DC / Impedance Bias Level is selected from the Loop Type sub-screen, the *loop* can be configured to perform one cycle for each entry in a list of DC bias voltage levels. The specified bias is applied to each constant level DC or impedance *step* within the *loop*, but only if DC scan value has been selected from the Scan Setup.

☞ Scan Setup for DC Bias Scanning Loop, Section 5.9.2.1.

The Loop Setup sub-screen for this *loop type* is as follows:



The fields at the left of this sub-screen are used to generate the list of AC amplitudes at the right, which can then be directly edited, in case specific values are required. The fields are:

Voltages are:

This field applies to all the voltage fields in this sub-screen, so that they can be defined relative to an appropriate base value.

☞ Relative Values, Section 5.8.4.1, but special considerations apply to the following:

vs. Previous	This refers to the last *step* before the *loop*, not the previous *step* within the *loop*.
vs. Open circuit	This refers to the most recent open circuit *step*, even if it is within the *loop*.

Scan DC bias level between

If this radio button is selected, the interval between two DC bias voltages is divided into a series of values. The fields under this button are:

Start

The DC bias to be applied on the first cycle round the *loop*.

End

The DC bias to be applied on the last cycle round the *loop*.

Step

The change of DC bias between successive cycles, until the End value is reached.

If this radio button is selected, the Points / decade and Total Points fields will be greyed out but will display appropriate values. If a value is specified in this field, the Total Points field will be recalculated, giving the points required between the Start and End values.

Points / decade

The number of values to be applied at logarithmic intervals during each decade of DC bias change.

If this radio button is selected, the Step and Total Points fields will be greyed out but will display appropriate values. If a value is specified in this field, the Total Points field will be recalculated, giving the points required between the Start and End values.

Total Points

The number of values to be applied between the Start and End values.

If this radio button is selected, the Step and Points / decade fields will be greyed out but will display appropriate values. If a value is specified in this field, the Step field will be recalculated, giving the change of DC bias between successive cycles.

Repeat for each DC bias level (V)

This radio button enables the list of DC bias levels underneath it to be directly edited, in case specific values are required. Otherwise, the list is greyed out and contains the values calculated from the fields on the left**.**

New values can be typed or pasted in, separated by any of the following delimiters:

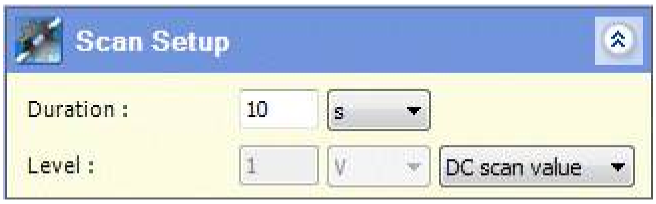
Tab
Space
New line
Semi-colon (;)
Comma (,) unless it is used as the decimal separator character.

When the screen is re-displayed, the delimiters will be converted to line breaks so that each value appears on a new line.

5.9.2.1 Scan Setup for DC Bias Scanning Loop

A constant level DC or impedance *step* under a DC bias scanning *loop* can be optionally configured to take its DC level from the *loop* as follows:

1. Click on the *step*, in the left-hand navigation panel, to display the sub-screens for the *step* configuration.
2. In the Scan Setup sub-screen, set the Level, or DC Level field to DC scan value as follows:



The fields for entering the value and units have become greyed out because the *step* takes its DC bias level from the *loop*.

NOTE: DC scan value should only be specified for a step that is inside a DC bias scanning loop, otherwise the experiment will not run.

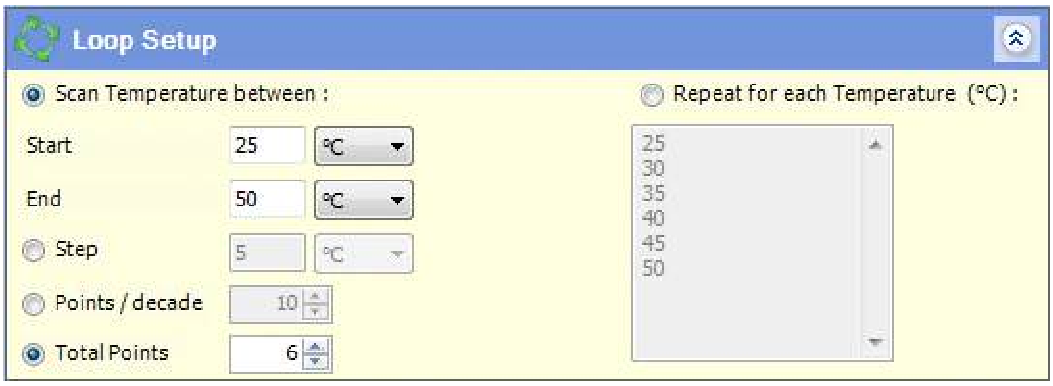
NOTE: Any *step type* may be included in a DC bias scanning *loop*, but only constant level DC or impedance *steps* can take values from the *loop*, otherwise the Scan Setup sub-screen does not contain the option to select DC scan value, and the *step* uses its own specified voltage level.

5.9.3 Temperature Loop

When a *loop* is selected from the left-hand navigation panel, and Scan Temperature is selected from the Loop Type sub-screen, the *loop* can be configured to perform one cycle for each entry in a list of temperatures. A Temperature Settling *step* is automatically inserted as the first *step* in the *loop*, and the experiment will generally remain within this *step* until the sample has reached the specified temperature.

☞ Temperature Settling Step, Section 5.9.3.1.

The Loop Setup sub-screen for this *loop type* is as follows:



The fields at the left of this sub-screen are used to generate the list of temperatures at the right, which can then be directly edited, in case specific values are required. The fields are:

Scan Temperature between

If this radio button is selected, the interval between two temperatures is divided into a series of values. The fields under this button are:

Start

The temperature to be applied on the first cycle round the *loop*.

End

The temperature to be applied during the last cycle round the *loop*.

Step

The change of temperature between successive cycles, until the End value is reached.

If this radio button is selected, the Points / decade and Total Points fields will be greyed out but will display appropriate values. If a value is specified in this field, the Total Points field will be recalculated, giving the points required between the Start and End values.

Points / decade

The number of values to be applied at logarithmic intervals during each decade of temperature change (in K so that the lower end of the scale approaches zero).

If this radio button is selected, the Step and Total Points fields will be greyed out but will display appropriate values. If a value is specified in this field, the Total Points field will be recalculated, giving the points required between the Start and End values.

Total Points

The number of values to be applied between the Start and End values.

If this radio button is selected, the Step and Points / decade fields will be greyed out but will display appropriate values. If a value is specified in this field, the Step field will be recalculated, giving the change of temperature between successive cycles.

Repeat for each Temperature (°C)

This radio button enables the list of temperatures underneath it to be directly edited, in case specific values are required. Otherwise, the list is greyed out and contains the values calculated from the fields on the left**.**

New values can be typed or pasted in, separated by any of the following delimiters:

Tab
Space
New line
Semi-colon (;)
Comma (,) unless it is used as the decimal separator character.

When the screen is re-displayed, the delimiters will be converted to line breaks so that each value appears on a new line.

5.9.3.1 Temperature Settling Step

When a *loop* is selected from the left-hand navigation panel, and Scan Temperature is selected from the Loop Type sub-screen, a Temperature Settling *step* appears as the first *step* within the *loop*, above any other *steps* that may already exist. If a new temperature scanning *loop* is being added, there will be a Temperature Settling *step* followed by a single undefined *step* as follows:

1: Temperature Settle
2: Step

You can click on the undefined *step* and give it any *step type*.

The Temperature Settling *step* belongs to the General category, and the default graph types can be specified from the Graph Preferences, but it does not appear in the list of *step types* when adding a new *step*. A Temperature Settling *step* cannot be added to an *experiment* Setup in the usual way. It can only exist within a temperature scanning *loop*, where it appears automatically.

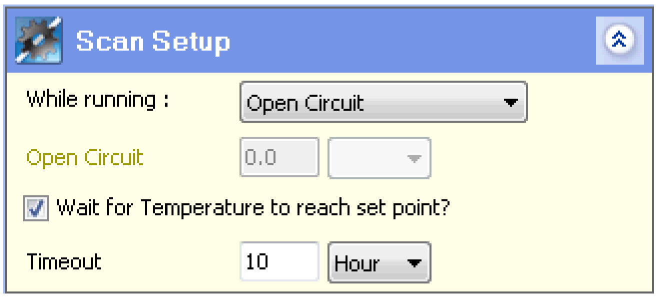
☞ Graph Preferences, Section 4.1.3.

☞ Step Types, General, Section 5.8.1.

When you click on a Temperature Settling *step* in the left-hand navigation panel, a Step Setup screen appears with all the appropriate sub-screens, which can be configured to take measurements in the usual way.

Step Setup, Section 5.7.

The Scan Setup sub-screen for a Temperature Settling *step* is as follows:



The fields are:

While running

This represents the signal to be applied to the sample while the *step* is running. The options are:

Open circuit
Constant Voltage

Sections 5.8.4.4 and 5.8.4.5.

Open Circuit / Voltage

This field has the appropriate title, depending on the selection from the previous field, and represents the signal level as follows:

Open circuit	The field is greyed out because no signal is applied.
Voltage	Specify a voltage signal in the appropriate units, relative to an appropriate base value. Relative Values, Section 5.8.4.1.

Wait for Temperature to reach set point?

If this box is checked, the *step* continues running until the sample reaches the temperature specified for the current cycle of the *loop*. If the sample fails to reach the specified temperature, the *step* will continue until it reaches the specifed Timeout.

If the box is not checked, the *step* will not wait for the temperature to be reached and will continue to the next *step* in the *loop*. In that case, the *loop* behaves the same as a standard *loop*, with one cycle for each specified temperature, and the sample progresses toward the temperature during the remaining *steps* in the *loop*.

This box effectively gives you the choice to run the *loop* with or without temperature scanning.

NOTE: The temperature is considered to have reached the set point when the latest measurement is within a specified tolerance value of the set point, or when a collection of the latest measurements has a standard deviation below a specified value. The temperature may be measured by a thermocouple directly on the sample, or in the space between the sample and the heating or cooling element. These criteria are defined in the Temperature Stability settings for the controller.

☞ Temperature Stability, Section 4.2.4.3.

Timeout

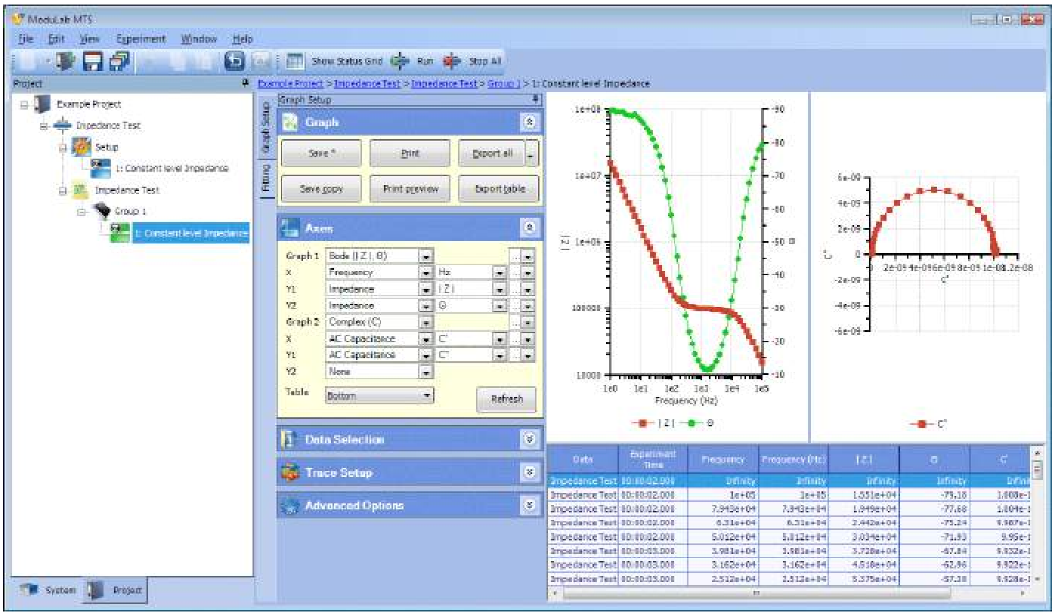
The timeout to be applied if the box has been checked to Wait for Temperature to reach set point.

5.10 DATA

When an *experiment* is run, a *data* item representing the results will appear in the left-hand navigation panel, with a structure of sub-items based on the structure of the *experiment*. When an item in the *data* structure is selected, measurements will appear in the right-hand window in the form of graphs and a tabulated list, depending on the configuration of the Axes sub-screen.

☞ Axes, Section 5.10.2.

The graphs and tabulated list will be updated as the *experiment* progresses and new measurements are taken, until the activity represented by the selected item is complete. Each item in the *data* structure is linked to a corresponding item in the *experiment* structure. For example, the following structure has a *data* item called Constant Level Impedance, and when selected it displays the results of the corresponding *step* in the *experiment*.



The *data* structure in this example is as follows:

- At the top level there is the *data* file name that is specified when the *experiment* is run.

  ☞ Start Experiment, Section 5.2.2.

- At the next level there is the core module, identified by the name specified in the Instrument Group Setup.

☞ Instrument Group Setup, Section 4.2.3.

- At the next level there is the *step*, identified by the *step type*.

NOTE: When a *project* is closed and re-opened, the core module will not appear in the *data* structure if there is only one of them. Also a *loop* will not appear if there is only one pass through the *loop*.

The sub-screens in the *data* screen are described in the following sub-sections:


☞ Graph, Section 5.10.1.

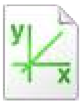

☞ Axes, Section 5.10.2.


☞ Data Selection, Section 5.10.3.

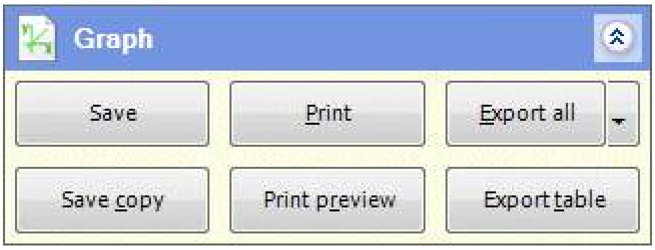

☞ Trace Setup, Section 5.10.4.


☞ Advanced Options, Section 5.10.5.

5.10.1 Graph



This sub-screen in the *data* screen contains a set of buttons so that you can save, print and export the currently displayed results.

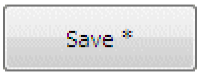


The buttons are as follows:

Save

Save the *data* as a Graph File which appears in the navigation panel. If this button is used more than once, the Graph File is overwritten.

☞ Graph File, Section 5.11.3.



An asterisk appears alongside the Save button if any changes have been made to the graph, since it was last saved, by editing the associated sub-screens (Axes, Data Selection, Trace Setup and Advanced Options). The asterisk disappears next time the Save button is used.

Save Copy

Save the *data* as a Graph File which appears in the navigation panel. This button is the same as the Save button, but in the Graph File, which has the same set of buttons, it has a different functionality.

Print

Open a print dialogue box and print the displayed graph. If there are two graphs they will be printed on separate pages.

Print Preview

Display a preview of the graphs before printing.

Export All

Export the *data* as an appropriate file type, depending on your selection from the list box at the right of the button. The options are:

Text	Export the *data* as a CSV file, which appears in the navigation panel, and display the results in the default application for this file type (for example Excel). The complete *data set* is exported, regardless of the displayed table. This is the default option, and is used if you click the button without selecting anything from the list box.
Zplot	Export the *data* to Zplot®, a software package for electrochemical impedance spectroscopy. The *data* will appear in Zview, if installed. (Must be version 3.1c or later)
Corrware	Export the *data* to Corrware®, a software package for electrochemical data acquisition, for corrosion analysis. The *data* will appear in Cview, if installed. (Must be version 3.1c or later)

Export Table

Export the *data* as a CSV file, which appears in the navigation panel, and display the results in the default application for this file type (for example Excel). The *data* is filtered so that a maximum of 2000 points are exported.

You can close the application and open it again from the File Information dialogue box.

☞ Filenames and Extensions, Section 2.3.

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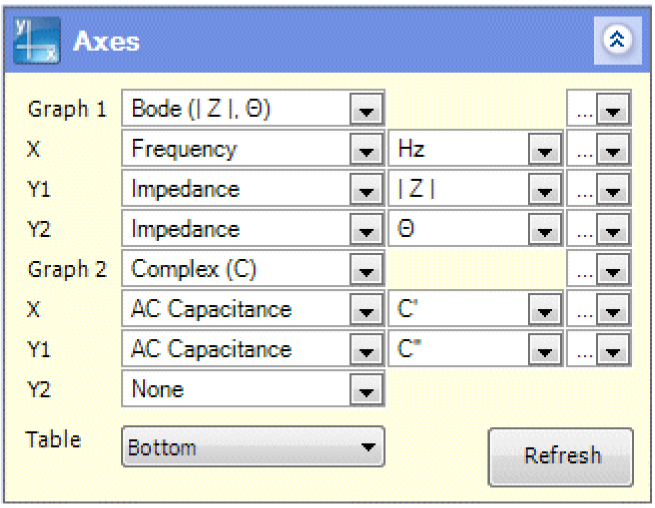
5.10.2 Axes

This sub-screen in the *data* screen enables you to specify the axes on which the *data* is to be displayed. By default they will be the same as the Graph Setup for the *step* in which the *data* was created.

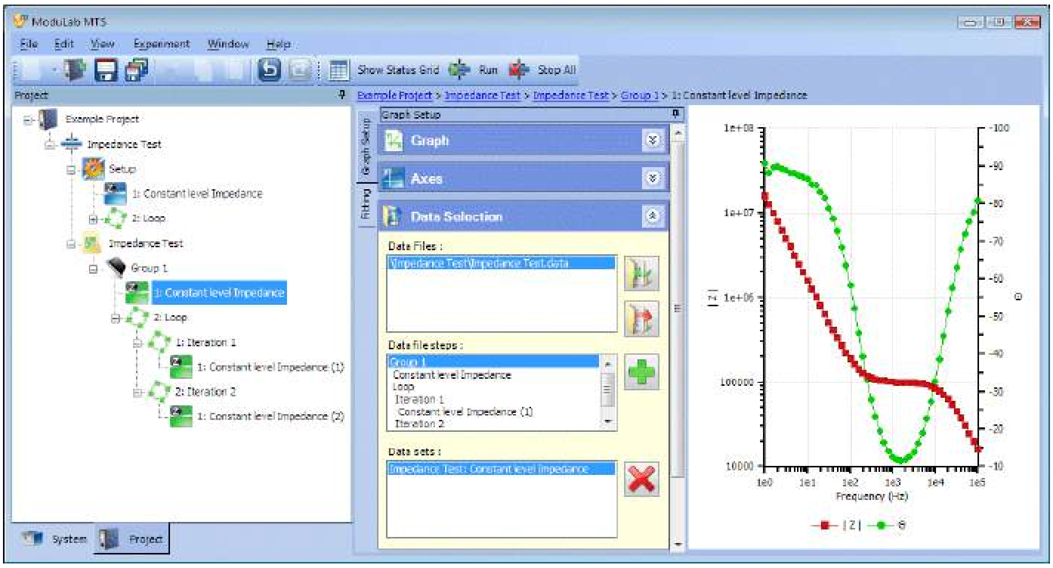


The fields follow the general layout of graphic displays.

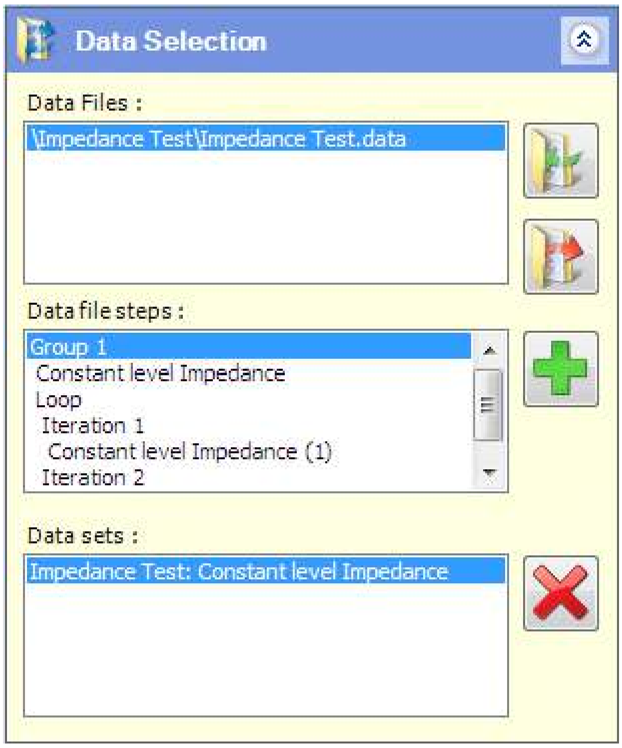
☞ Layout of Graphic Displays, Section 5.11.1.

5.10.3 Data Selection

This sub-screen in the *data* screen enables you to select the *data* to be displayed. The sub-screen, together with the left-hand navigation panel and graph, is as follows:



An enlarged view of the Data Selection sub-screen is as follows:



This example shows what the sub-screen might look like after running an *experiment* just once and selecting a *step* called Constant Level Impedance within a *data* folder called Impedance Test. The pathname of a *data* file called Impedance Test.data appears in the upper panel, and a series of *steps* appears in the middle panel, under the group name Group 1. The first *step* is Constant Level Impedance, then there is a *loop* with two iterations, each containing a *step* called Constant Level Impedance followed by the iteration number.

The lower panel displays the *step* that has been selected from the left-hand navigation panel, in this case the one outside of the *loop*, and this is the *step* that appears in the graphic display.

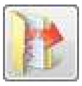
The fields are as follows:

Data Files

This window displays a list of *data* files generated by *experiments*. Initially there is just one file corresponding to the results of this *experiment*, but other files can be added, for the purpose of comparison. The additional files can be created by running the same *experiment* several times, or by running other *experiments*, and then the *data* files can be imported into this sub-screen. If a file is no longer required in the list, it can be removed.

When you click on a file, the list of *steps* within the file will appear in the Data file steps window.

This button opens a dialogue box so that you can browse for a *data* folder and add it to the Data Files window. Only folders are displayed, not the files within them, and you can only add folders with the DATA extension. If you try to add any other folder, the system will return an error.



This button removes the selected folder from the Data Files window.

Data file steps

This window displays the complete list of *steps* within the file that has been selected in the Data Files window. You can select any *step* from the list and add it to the Data sets window, for graphic display.

This button adds the selected *step* in the Data file steps window to the Data sets window.

Data Sets

A *data set* is the *data* generated by a single *step* in the *experiment*, and this window contains a list of *data sets* to be displayed in the graphs and tabulated lists. By default, it contains a single *data set* generated by this *experiment*, but other *data sets* can be added from the Data file steps window.

This button removes the selected *step* from the Data sets window.

5.10.4 Trace Setup

This sub-screen in the *data* screen enables you to define the appearance of the graphs, in terms of line types, colours and symbols.

The fields are as follows:

Style

This list box displays lines or symbols on the graph, as follows:

Auto	Automatically choose to display *data* as lines or symbols on the graph, depending on the number of measurement points.
Lines	Display *data* as lines on the graph.
Symbols	Display *data* as symbols on the graph. There will be one symbol for each measurement taken.
Both	Display *data* as both lines and symbols.

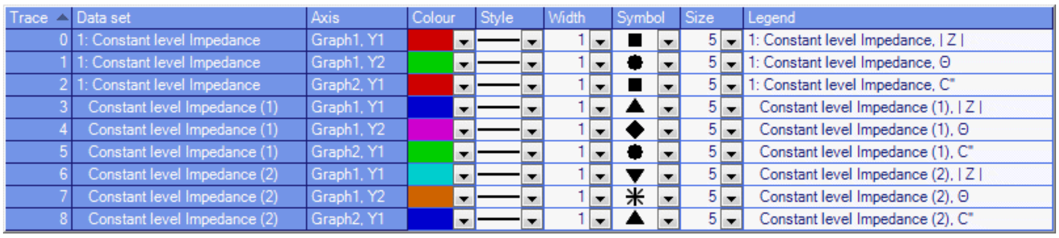
Colours

This list box specifies how colours are to be displayed on the graph, as follows:

Colour	Change all traces to their default colours
Black	Change all traces to black.

Advanced Trace Setup

When this list box is clicked, a popup window appears as follows:



Trace	Data set	Axis	Colour	Style	Width	Symbol	Size	Legend
0	1: Constant level Impedance	Graph1, Y1			1		5	1: Constant level Impedance, | Z |
1	1: Constant level Impedance	Graph1, Y2			1		5	1: Constant level Impedance, Θ
2	1: Constant level Impedance	Graph2, Y1			1		5	1: Constant level Impedance, C"
3	Constant level Impedance (1)	Graph1, Y1			1		5	Constant level Impedance (1), | Z |
4	Constant level Impedance (1)	Graph1, Y2			1		5	Constant level Impedance (1), Θ
5	Constant level Impedance (1)	Graph2, Y1			1		5	Constant level Impedance (1), C"
6	Constant level Impedance (2)	Graph1, Y1			1		5	Constant level Impedance (2), | Z |
7	Constant level Impedance (2)	Graph1, Y2			1		5	Constant level Impedance (2), Θ
8	Constant level Impedance (2)	Graph2, Y1			1		5	Constant level Impedance (2), C"

This window contains a number of properties that you can apply to the lines and symbols on the graph. There is a header row, followed by one row for each *data set*, graph and vertical axis that is displayed. In this example there are three *data sets* (listed in the Data Selection sub-screen) and two graphs with three vertical axes between them, (defined in the Axes sub-screen) so there are nine rows altogether, numbered from 0 to 8.

☞ Data Selection, Section 5.10.3.

☞ Axes, Section 5.10.2

The fields are as follows:

Trace

The trace number, starting at 0 and incrementing by 1 for each successive row.

Data Set

The *data set* name, according to the list in the Data Selection sub-screen (which defaults to the item selected from the left-hand navigation panel).

Axis

The graph number (Graph 1 or Graph 2) and the axis, (Y1 or Y2).

Colour

The colour of the trace. The list box displays a colour palette.

Style

The line style used for the trace. The list box displays a list of styles (continuous, dotted, dashed, etc.)

Width

The line width used for the trace. The list box displays a list of numeric values from 1 to 5.

Symbol

The symbol used for each *data* point on the trace. The list box displays a list of symbols (circles, squares, etc.)

Size

The size of the selected symbol. The list box displays a list of odd numbers from 1 to 15.

Legend

The legend for the axis. The text field defaults to the selected units, but you can change it.

5.10.5 Advanced Options

This sub-screen in the *data* screen enables you to specify options for *data* reduction, to speed up the drawing of graphs that would otherwise involve a large number of measurement points.

The fields are as follows:

Measurement types

This list box specifies the type of measurement to which filtering is applied. The options are:

Auto	The system automatically selects All Measurements or Impedance Only, depending on which one is most appropriate. This is the default option.
All measurements	Apply *data* filtering to all measurements.
Impedance only	Discard all DC measurements and apply *data* filtering to the impedance measurements only.

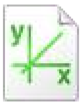
Data reduction

This list box specifies the type of *data* filtering to be applied. The options are:

None	Display all *data* points without filtering. This option should not be used if there are more than a million points, or while the *experiment* is running.
First	Display the first 2000 points.
Last	Display the last 2000 points. When 2000 points have been accumulated, the oldest ones will be discarded.
Regular	Display every *n*’th point, where *n* is calculated so that 2000 points are displayed.

Random	Divide the *data* into 2000 sections, each containing an equal number of points, and display one point at random from each section.
MinMax	Divide the *data* into 1000 sections, each containing an equal number of points, and display the minimum and maximum values from each section.
RegularTime	Display every *n*'th point, where *n* is calculated so that 2000 points are displayed, each from an equal time interval.
MinMaxTime	Divide the *data* into 1000 equal time intervals, and display the minimum and maximum values from each interval.
Auto	The system automatically chooses an option from the list, depending on what is most appropriate for the *data*, which may include DC or impedance measurements. This is the default option.

5.11 GRAPHIC DISPLAYS



Graphic displays are generated by the ModuLab XM system and are available both during and after an *experiment*.

☞ Data, Section 5.10.

The *data* generated by *experiments* is divided into *data sets* for each *step*. The layout of the graphs in each *data set* is defined in the Graph Setup sub-screen for the *step*, and there is an option to use the default layout for the *step type*, defined in the Graph Preferences screen. The layout can subsequently be changed, when the results have been generated, using the Axes sub-screen. In each of these screens, where graphs are defined, the general layout is the same.

☞ Graph Setup, Section 5.7.6.
☞ Graph Preferences, Section 4.1.3.
☞ Axes, Section 5.10.2.
☞ Layout of Graphic Displays, Section 5.11.1.

Data from other *experiments* can be retrieved into the *data* file, including *data* that has been generated by users of other ModuLab XM systems. Sub-sets of *data* from multiple *experiments* can be compared with each other, so that this feature provides a powerful tool for data analysis.

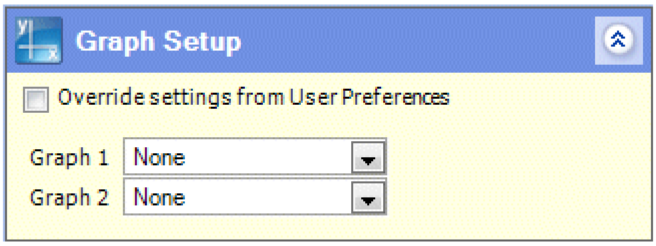
☞ Data Selection, Section 5.10.3.

Data from any *experiment* can also be displayed using the Graph file. This has the same graphic display features as the *data* file, but it can be manually added to the system and does not need to be generated by an *experiment*. It also makes the *data* available to *reports*.

☞ Graph File, Section 5.11.3.

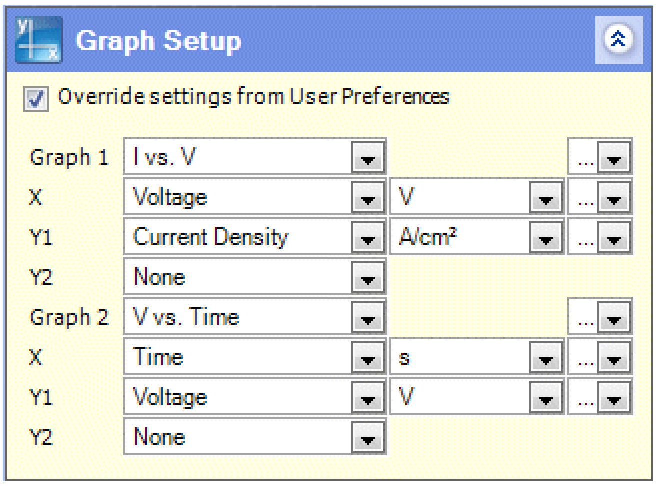
5.11.1 Layout of Graphic Displays

Graphic displays are defined in a number of different dialogue boxes in the ModuLab XM software, but they have the same general layout, with fields for defining two graphs called Graph 1 and Graph 2. The following screen defines the Graph Setup for a *step* and includes an option to use the settings from the User Preferences.

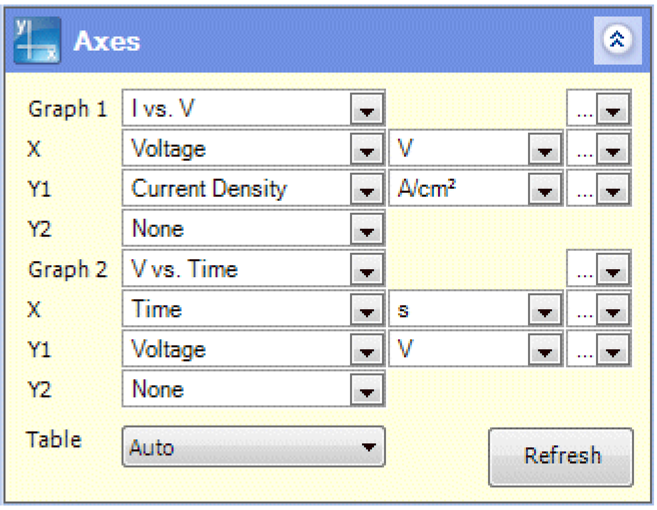


☞ Graph Setup, Section 5.7.6.

When an entry is selected in the Graph 1 and Graph 2 fields, the display is expanded with additional fields to define the axes as follows:



When an *experiment* has been run and results are generated, the Axes sub-screen is available so that you can change the displays.



The Axes sub-screen is the same as the Graph Setup sub-screen, except for the following:

- It doesn't have the Override settings from User Preferences check box because the option to override these settings has already been decided in the Graph Setup.
- It has a Table field to display tabulated data.
- It has a Refresh button to redisplay the graphs and tabulated data after changing the fields.

The complete set of fields in the Graph Setup and Axes sub-screens is as follows:

Override settings from User Preferences

If this box is checked, the selections in the Graph Setup screen are used to define the graphs, otherwise they conform to the defaults for the *step type*, defined in the Graph Preferences screen.

☞ Graph Preferences, Section 4.1.3.

If the entries in the Graph Setup screen are to be used for an *experiment*, this box should always be checked.

If the box is cleared, the entries in the Graph Setup screen are ignored, and when the *experiment* is run and the results are produced, the Axes screen will conform to the Graph Preferences, not the Graph Setup, but the fields can be changed.

This check box does not affect the Table field, which exists only in the Axes screen, and uses the Graph Preferences if the Auto option is selected.

Graph 1, Graph 2

The type of graph to be displayed. Two graphs can be displayed simultaneously, with axes depending on the selections from these fields. The options for DC plots are as follows:

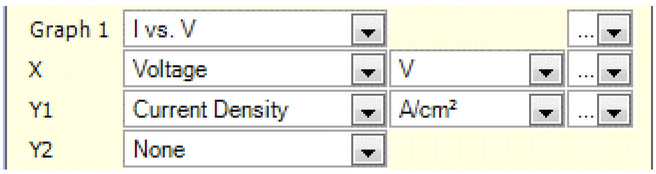
None
V vs. Time
I vs. Time
Q vs. Time
V + I vs. Time
V vs. I
I vs. V
V vs. Log (I)
Log (I) vs. V
V + Temp vs. Time
I + Temp vs. Time

The additional options for impedance plots are as follows:

Bode (|Z|, θ)
Bode (Z′, Z″)
Complex (Z)

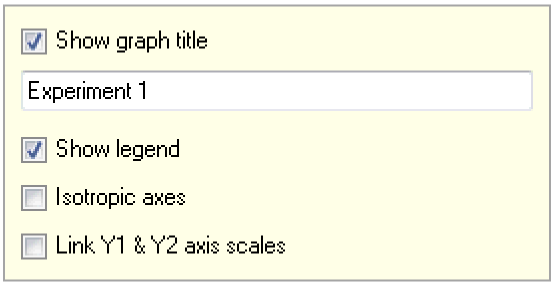
|Z| + θ vs. V
|Z| + θ vs. Ampl
Bode (|Y|, θ)
Bode (Y′, Y″)
Complex (Y)
Bode (|C|, θ)
Bode (|C|, Tan δ)
Bode (C′, C″)
Complex (C)
Mott Schottky
Bode (|ε|, θ)
Bode (|ε|, Tan δ)
Bode (ε′, ε″)
Complex (ε)
|ε| + θ vs. V
|ε| + θ vs. Ampl
Bode (|εr|, θ)
Bode (|εr|, Tan δ)
Bode (εr′, εr″)
Complex (εr)
Bode (|M|, θ)
Bode (|M|, Tan δ)
Bode (M′, M″)
Complex (M)
Bode (|Mr|, θ)
Bode (|Mr|, Tan δ)
Bode (Mr′, Mr″)
Complex (Mr)

If anything other than “None” is selected, a drop-down box appears alongside the Graph 1 or Graph 2 list box, and the display is expanded with the X, Y1, Y2 fields as follows:



Graph 1, Graph 2 (details)

The drop-down box alongside the Graph 1 or Graph 2 list box displays the graph configuration details as follows:



The fields are:

Show Graph Title

If this box is checked, the title specified in the text box will appear above the graph.

Show Legend

If this box is checked, a legend will appear under the graph, representing each trace.

Isotropic Axes

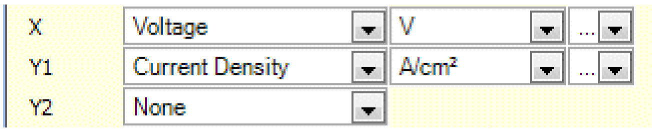
If this box is checked, the axes are scaled so that the measurement units occupy an equal length on the X, Y1 and Y2 axes.

Link Y1 & Y2 axis scales

If this box is checked, the Y2 axis is mapped onto the Y1 axis and uses the same scale, so the left-hand vertical axis represents both Y1 and Y2. This box is checked by default for graph types representing real and imaginary values.

X, Y1, Y2

These represent the horizontal axis (X), the vertical axis (Y1) and a second vertical axis (Y2) which may be used in some graphs.



For each of these fields that displays a variable other than “None”, two additional fields appear to the right, a list box of units, and a drop-down box for configuration of the axis with labels, limits, tick marks, etc.

Each axis defaults to an appropriate setting for the graph type that has been selected in Graph 1 or Graph 2, but they can be changed by selecting the following options:

None
Time
Voltage
Current Density
Charge Density
Power Density
Resistance
Temperature
Range
Frequency
Impedance
Admittance
AC Capacitance
Permittivity
Rel Permittivity
Modulus
Rel Modulus
AC Voltage
AC Current

The Y2 axis defaults to None for graph types that involve two axes, but it defaults to an appropriate variable for graph types that require three axes, for example Current Density if the graph type is V + I vs. Time.

X, Y1, Y2 (units)

This field appears to the right of any axis field (X, Y1 or Y2) that has not been set to None. It has a drop-down list box of units which depend on the variable being displayed by the axis. For example, if the axis represents time, the available units are:

ms
s
Minute
Hour
Day

X, Y1, Y2 (details)

This drop-down box appears to the right of the units field for any axis field (X, Y1 or Y2) that has not been set to None. It displays a detailed configuration of the axis.

☞ Axis Details, Section 5.11.1.1.

Table

This list box appears at the bottom of the Axes sub-screen (but not the Graph Setup sub-screen) as follows:

Tabulated data may be displayed alongside the graphs at the appropriate positions. The options from the list box are as follows:

None	Do not display tabulated data.
Auto	Display tabulated data at the default positions specified in the Graph Preferences sub-screen in the User Preferences. ☞ Graph Preferences, Section 4.1.3.
Right	Display tabulated data to the right of the graphs.
Bottom	Display tabulated data below the graphs.

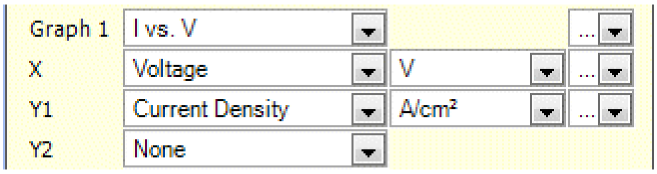
Refresh

This button appears at the bottom of the Axes sub-screen (but not the Graph Setup sub-screen), and refreshes the graphs and tables according to any changes that have been made.

An amber warning icon appears alongside the button when changes have been made to the screen and the graphs need to be refreshed.

5.11.1.1 Axis Details

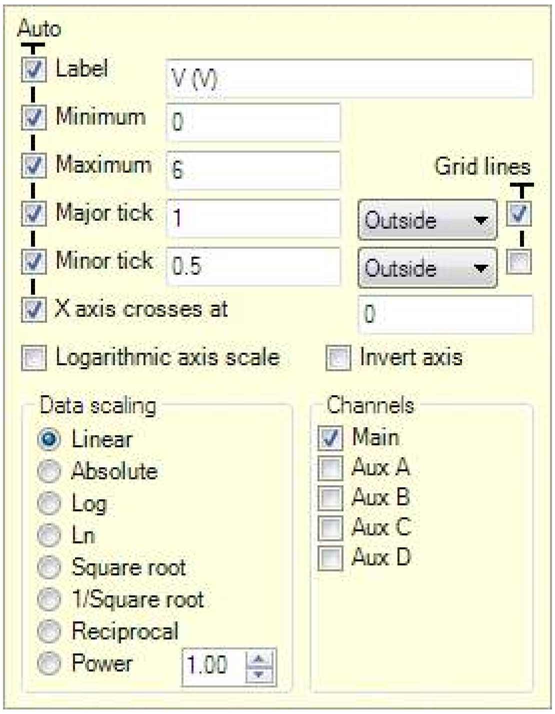
The Graph Setup and Axes sub-screens contain a set of fields representing the graph type and the X, Y1 and Y2 axes as follows:



☞ Layout of Graphic Displays, Section 5.11.1.

Each axis field with an entry other than None has two additional fields, one for the units, and the other for additional details about the axis.

The drop-down box on the details field varies according to the quantity represented by the axis, but for Voltage it is as follows:



The default values for some of these fields depend on the graph type. For example, on a Bode plot where the Graph 1 field is Bode (|Z|, θ), the Logarithmic axis scale box will be checked for the impedance magnitude and frequency axes, but unchecked for the phase angle axis.

In this display, the fields are as follows:

Auto

In this group of fields, a check box is followed by one or more text or numeric fields. The boxes are normally checked, indicating that the fields are automatically given appropriate values, according to the displayed data, but if the fields are changed the boxes automatically become unchecked.

The fields are:

Label

The axis label, which defaults to the variable and units represented by the axis.

Minimum

The minimum value of the variable to be displayed on the axis.

Maximum

The maximum value of the variable to be displayed on the axis.

Major tick

The interval at which major tick marks and values appear on the axis. The numeric field is followed by a list box with the following options:

None	Tick marks are not displayed.
Inside	Tick marks are displayed inside the axis.
Outside	Tick marks are displayed outside the axis.
Cross	Tick marks are displayed both inside and outside the axis.

Minor tick

The interval at which minor tick marks, without values, appear on the axis. The numeric field is followed by a list box, same as for major ticks.

X axis crosses at

This field specifies the value of the Y axis where the X axis crosses it. This is useful, for example, when placing the axis on zero, between positive and negative limits.

Logarithmic axis scale

The axis has a logarithmic scale. This box is checked by default if the axis for the graph type is normally logarithmic. For example, in a Bode plot, the impedance and frequency are logarithmic, but the phase angle is linear, so the box is checked or unchecked depending on the axis that it represents. The sign is ignored if the value is negative.

Invert axis

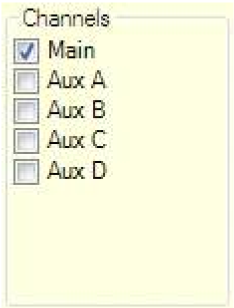
If this box is checked, the axis will be inverted so that the values increase in the reverse direction. (X axis from right to left, Y axis from top to bottom).

Data Scaling

The scaling of the data, before it is plotted, which can be one of the following, selected from a radio button:

Linear	No scaling applied
Absolute	Negative values converted to positive
Log	Logarithm to the base 10
Ln	Logarithm to the base e
Square root	
1/Square root	
Reciprocal	
Power	Scale the axis according to the power specified in the field alongside the radio button, for example: 2 Squared 3 Cubed 0.5 Square root -1 Reciprocal

Channels



This group of fields represents the channels to be displayed as separate traces on the graph, each with its own legend. A check box is available for each channel, and any number of them can be checked, as long as at least one of them is checked.

This group appears for all axes except those representing the following variables:

Current density
Temperature
Time
Range

The fields within the group depend on the variable represented by the axis, as follows:

Main

If this box is checked, the graph displays the measurements taken from the main channel (Vhi, Vlo). This field appears in the Channels group for all axis variables that display the group.

Aux A, Aux B, Aux C, Aux D

If any of these boxes are checked, the graph displays the measurements taken by the appropriate auxiliary channel.

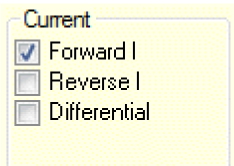
Measurements will only be available if they have been enabled from the Instrument Experiment Setup, by checking the appropriate boxes under Enable Auxiliary Voltage Inputs.

☞ Instrument Experiment Setup, Section 5.3.4.

These fields appear in the Channels group for axes representing the following variables:

Voltage
Impedance
Admittance
AC Voltage
AC Current

Current



This group of fields exists only for an axis representing current density, and has the following check boxes:

Forward I

The current density in the forward direction. This will be at the top of a pulse or step for a differential pulse or square wave.

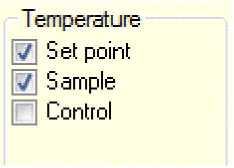
Reverse I

The current density at the bottom of a pulse or step for a differential pulse or square wave. This check box has no meaning for other *step types* because there is no reverse data.

Differential

The difference in current density between the top and bottom of a pulse or step, for a differential pulse or square wave. This check box has no meaning for other *step types* because there is no reverse data.

Temperature



This group of fields exists only for an axis representing temperature, and has the following check boxes:

Set point

The temperature specified in the scanning *loop*, so that the sample progresses toward this temperature.

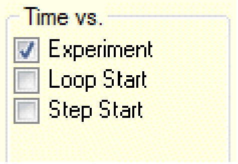
Sample

The temperature of the sample, measured by a thermocouple.

Control

The temperature of the heating or cooling device, measured by a thermocouple close to the heating or cooling element.

Time vs



This group of fields appears only for a time axis, and represents the offset of the zero value on the axis, which can be one of the following, selected from a check box:

Experiment

The time axis has the zero value at the beginning of the *experiment*.

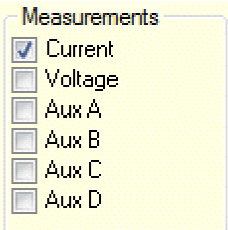
Loop Start

The time axis has the zero value at the beginning of the current iteration round a *loop*.

Step Start

The time axis has the zero value at the beginning of the current *step* or cycle.

Measurements



This group of fields appears only for a range axis, and represents the measurement ranges used during the experiment, according to their range numbers. The check boxes are:

Current

The current range used by the core module. This box is checked by default.

Voltage

The voltage range used by the core module.

Aux A, Aux B, Aux C, Aux D

The voltage ranges used by the auxiliary channels.

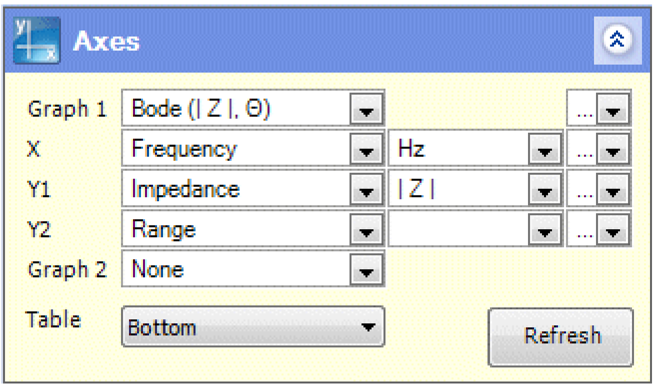
5.11.2 Measurement Ranges

When an experiment is running and generating data, and the core module changes from one voltage or current range to another, the system may record the range numbers so that they can be displayed in graphs and tables, together with the data.

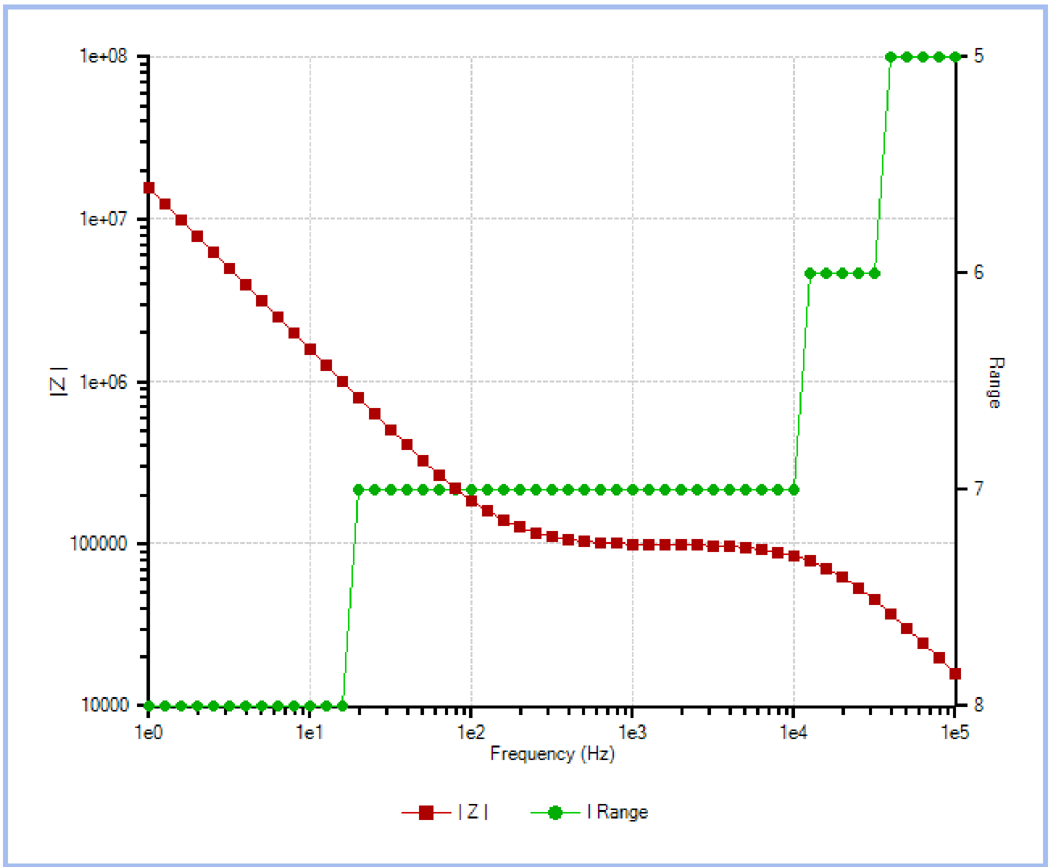
Normally, range numbers are only included in the data if they do not significantly slow down the data collection rate. However, if the Force recording range changes box is checked, in the Instrument Experiment Setup, range numbers will be included regardless of their effect on data collection.

☞ Instrument Experiment Setup, Section 5.3.4.

The range numbers can be displayed in graphs and tables, together with the data, by selecting the appropriate options in the Graph Setup and Axes sub-screens. Here is an example of an Axes sub-screen with Range selected as the Y2 axis and Bottom selected as the Table option:



This displays a graph and table as follows:



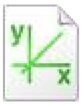
Data	Experiment Time	Frequency	Frequency (Hz)	| Z |	Range
FRA Test 2: Constant level Impedance	00:00:02.000	Infinity	Infinity	Infinity	5
FRA Test 2: Constant level Impedance	00:00:02.000	1e+05	1e+05	1.572e+04	5
FRA Test 2: Constant level Impedance	00:00:02.000	7.943e+04	7.943e+04	1.968e+04	5
FRA Test 2: Constant level Impedance	00:00:02.000	6.31e+04	6.31e+04	2.452e+04	5
FRA Test 2: Constant level Impedance	00:00:02.000	5.012e+04	5.012e+04	3.034e+04	5
FRA Test 2: Constant level Impedance	00:00:02.000	3.981e+04	3.981e+04	3.719e+04	5
FRA Test 2: Constant level Impedance	00:00:03.000	3.162e+04	3.162e+04	4.503e+04	6
FRA Test 2: Constant level Impedance	00:00:03.000	2.512e+04	2.512e+04	5.357e+04	6
FRA Test 2: Constant level Impedance	00:00:03.000	1.995e+04	1.995e+04	6.243e+04	6
FRA Test 2: Constant level Impedance	00:00:03.000	1.585e+04	1.585e+04	7.083e+04	6
FRA Test 2: Constant level Impedance	00:00:03.000	1.259e+04	1.259e+04	7.821e+04	6
FRA Test 2: Constant level Impedance	00:00:04.000	1e+04	1e+04	8.423e+04	7
FRA Test 2: Constant level Impedance	00:00:04.000	7943	7943	8.887e+04	7

In this *experiment*, the data has been generated from a Constant Level Impedance *step* where the impedance varies with frequency. This causes a change in the measured current, so that the range number changes when required. The range numbers are associated with voltage and current ranges in the Instrument Experiment Setup, so that the least sensitive ranges use the lowest range numbers.

By default, a Range axis displays only the current range, so that in this example there is only one trace associated with the Range axis, and only one Range column in the table. Additional traces and columns will appear if voltage or auxiliary channel options are selected in the Measurements group, in the Axis Details drop-down box.

☞ Axis Details, Section 5.11.1.1.

5.11.3 Graph File



A Graph file can be added to the Navigation panel, under a *project*, *experiment* or *folder*, to display *data* that has been generated by *experiments*. It has the same graphic display features as the *data* screen, but has the following additional functionality:

- It can be manually added to the system and does not need to be generated from an *experiment*. In this case, it initially accesses no *data*, and you have to browse through the filing system to find the *data* that you want to display.
- It can make the *data* accessible to *reports*.

☞ Data, Section 5.10.

☞ Reports, Section 5.13.

This feature enables you to create your own collections of *data* from different ModuLab XM *experiments* and store them in *folders* that are structured according to your requirements. It is also the most convenient way of displaying *data* that has been exchanged between users of different ModuLab XM systems.

To add a Graph file independently of an *experiment* and then display some *data*, proceed as follows:

1. Right-click on a *project*, *experiment* or *folder* in the navigation panel to display the drop-down menu.
2. Click on Add New, then Graph. A screen appears, similar to the Data screen, but the Data Selection sub-screen will be empty as follows:

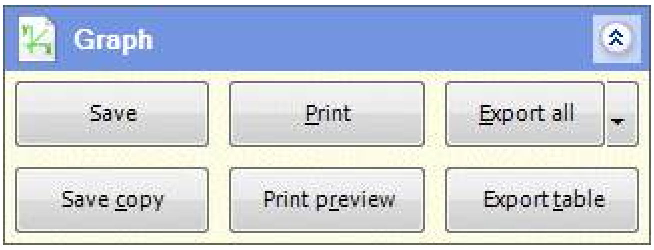
3. Browse the filing system and select the appropriate *data* file, then select the *data* to be displayed.

   ☞ Data Selection, Section 5.10.3.

To add a *graph* file from a *data* file and display the data:

1. Click on the *data* item, in the left-hand navigation panel. (The *data* item will be selected automatically if the *experiment* has just been run.)

   The *data* screen contains the Graph sub-screen as follows:



   ☞ Graph, Section 5.10.1.

2. Click on the Save or Save Copy buttons to add a Graph file containing all the results from the *data* item.

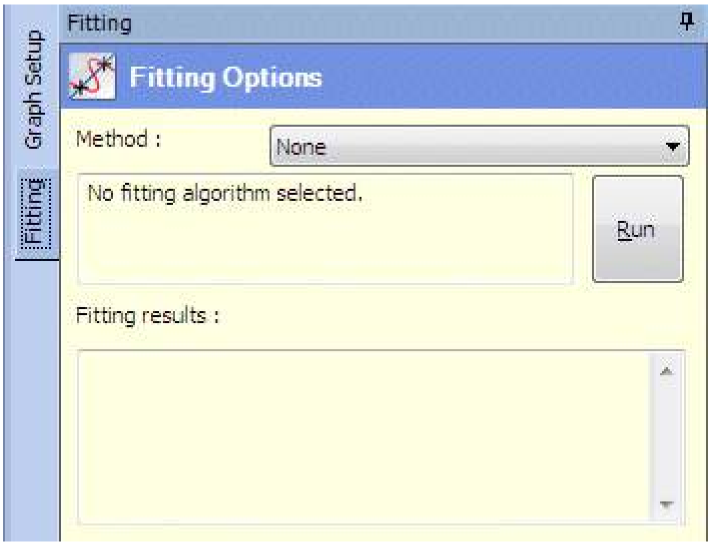
NOTE: The Graph file displays the same sub-screens as the Data screen, including the Graph sub-screen. The Save button is the same, overwriting the existing Graph file, but the Save Copy button creates a new Graph file in the navigation panel, alongside the existing one, with the filename appended by a number. The Save and Save Copy buttons are both the same in the Data screen, overwriting the existing file.

5.12 MATHEMATICAL FUNCTIONS AND CIRCUITS (FITTING)

Graphical displays generated by ModuLab XM can be represented by simple mathematical functions, including straight lines and circles, which are fitted to the results using statistical algorithms. It is also possible to construct electrical circuits representing the results.

To access these features of ModuLab XM, proceed as follows:

1. In the left-hand navigation panel, click on a *data* item. If there are no *data* items, you will need to generate one by running an *experiment*.
2. Display the results as the appropriate graph types, depending on the mathematical function to be fitted.
3. Click the Fitting tab, to the right of the navigation panel, to display the Fitting Options as follows:



The fields available in this screen depend on the Fitting Method, selected from the Method list box which contains the following options:

None	Do not fit any functions or circuits to the data.
Line	Fit a straight line through the data. ☞ Section 5.12.1.
Circle	Fit a circle to the data. ☞ Section 5.12.2.
Equivalent circuit	Fit an equivalent circuit to the data. ☞ Section 5.12.4. The circuit is drawn by the user and the model calculates the values of the components, including resistors, capacitors and inductors. This method can only be used for impedance data.

In all cases, data can be selected by clicking two points on a graph, and the model calculation will include all the data between the points. Alternatively, the calculation can be based on the complete set of data, so that no points need to be specified.

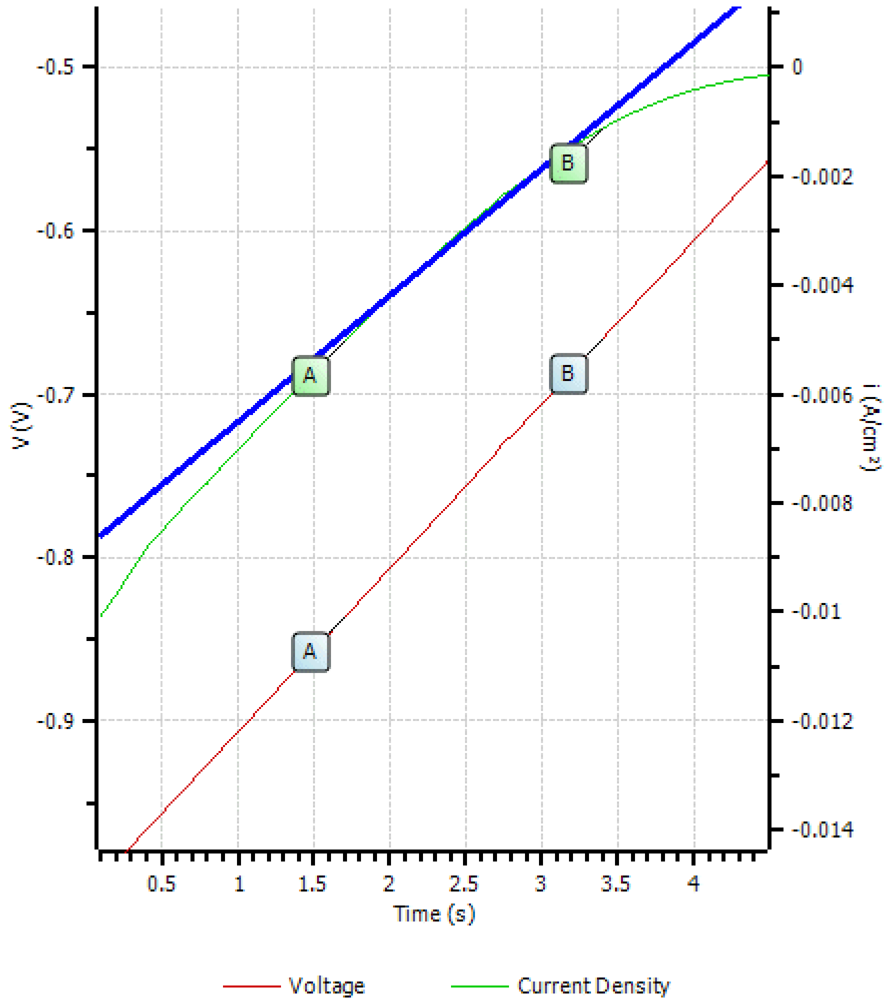
To select the data for fitting, proceed as follows:

1. Click the appropriate points on the graph. Each successive point will be labelled A, B, C etc. For most plots, only two points will be needed. If required, for greater precision, hold the cursor over a position on the graph and the X and Y values will appear, then click on the point.
2. If a point needs to be moved, hold the cursor on the label and drag it along the line of data. As the cursor moves, the label will display the X and Y values, which will animate as the values change. When you arrive at the required values, release the mouse and the label will re-appear.
3. If a graph contains two traces, for example voltage and current density against time, complementary labels will appear on the second trace, but only if the two traces are based on the same *data set*. The trace that is currently selected for fitting will have green labels, while the non-selected trace will have blue labels. If the second trace is selected, by clicking on a blue label, the colours will be reversed so that the blue labels turn green and the green labels turn blue.
4. When the points have been set up, select the required Method in the Fitting Options screen and set the appropriate options for the Method, then click the Run button. The plot will be fitted to the data, and the parameters will appear in the Fitting Results box, under the Run button.

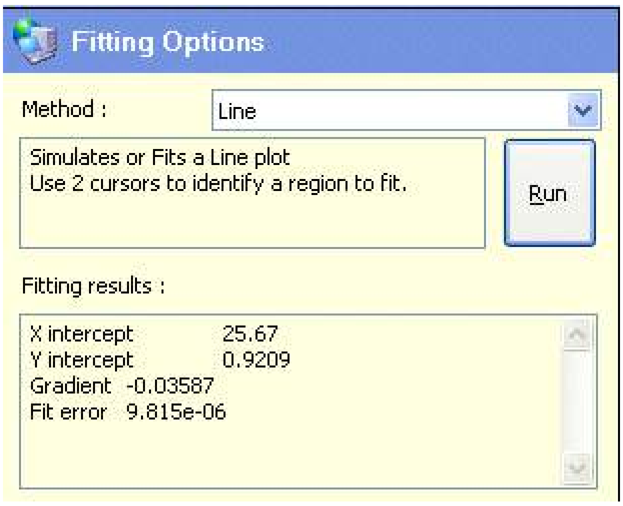
   ☞ Line and Circle Methods, Sections 5.12.1 - 5.12.2.

5. If the graph contains two traces, you can click a label on the second trace and click the Run button again, and the function will be fitted to the second trace.

The following example shows a result produced from a Linear Sweep (plotted as V + I vs. Time), with a straight line fitted between two points on the voltage trace.

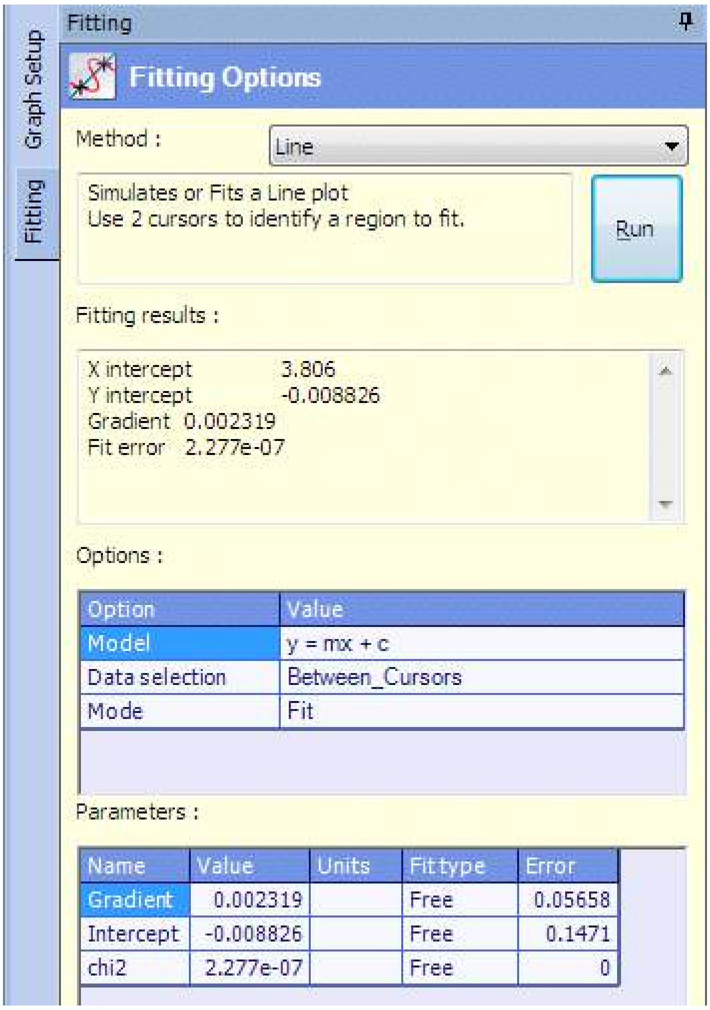


The line definition, in terms of the X and Y intercepts, gradient and fit error appear in the Fitting Results box as follows:



5.12.1 Line

The Line method in the Fitting Options screen fits a straight line through the data, as shown in the previous section. The Fitting Options screen is as follows:



The fields are:

Method

Defines the type of plot, in this case Line. The text box below this field gives instructions about how to use the cursors to identify the region where the plot is to be fitted.

Run

This button performs the calculation, and displays the results as a simulated trace on the graph and a set of values in the Fitting Results box.

Fitting Results

When the calculation is performed, this box displays the line definition as follows:

X intercept	The point where the plot crosses the X axis (Y=0)
Y intercept	The point where the plot crosses the Y axis (X=0). The constant *c* in the Model equation: y = mx + c
Gradient	The gradient *m* in the Model equation: y = mx + c
Fit error	The error introduced by the scattering of data points around the line, calculated from the Chi^2 test. A value of zero indicates a perfect fit.
Y intercept (ω=1)	The value of Y on an impedance plot where the X axis represents frequency, at the point where X = 1/2π Hz (angular frequency ω = 1 rad/sec). This result only appears for impedance plots.
Estimated C	Estimated capacitance, calculated as: C = 1 / Y intercept (ω=1)

Options

The following options are available:

Model

The model used for the line definition. Only one model is available for this Method:

y = mx + c

where:

y is the vertical axis measurement of a point on the plot.

x is the horizontal axis measurement of a point on the plot.

m is the gradient

c is the intercept on the y axis.

Data selection

This list box selects the range of data through which the line is to be fitted. The options are:

Between Cursors	Fit the line to all the data between two specified points on the graph.
All Points	Fit the line to all the data on the graph, so that there is no need to specify cursors.

Mode

This list box specifies how the model is applied to the data. The options are:

Fit	Fit the mathematical model to the data and calculate a set of parameters to produce simulated results.
Simulate	Evaluate the model from a set of parameters specified by the user, which may be an approximate representation of a previous fit.

Parameters

This table contains details of the parameters used to produce the simulated results. The parameters are listed in the Name column as follows:

Gradient	The gradient *m* in the model equation: y = mx + c
Intercept	The Y intercept ***c*** in the model equation: y = mx + c
Chi2	The fit error, based on the Chi^2 test. A value of zero indicates a perfect fit.

For each of these parameters, the remaining columns are as follows:

Value — The value of the parameter, which may be calculated by the system or specified by the user.

Units — The units in which the value is specified or calculated. This field depends on the selected Method:

- A list box of units, appropriate to the selected component, is available for an Equivalent Circuit.
- There are no units for the Line or Circle Method.

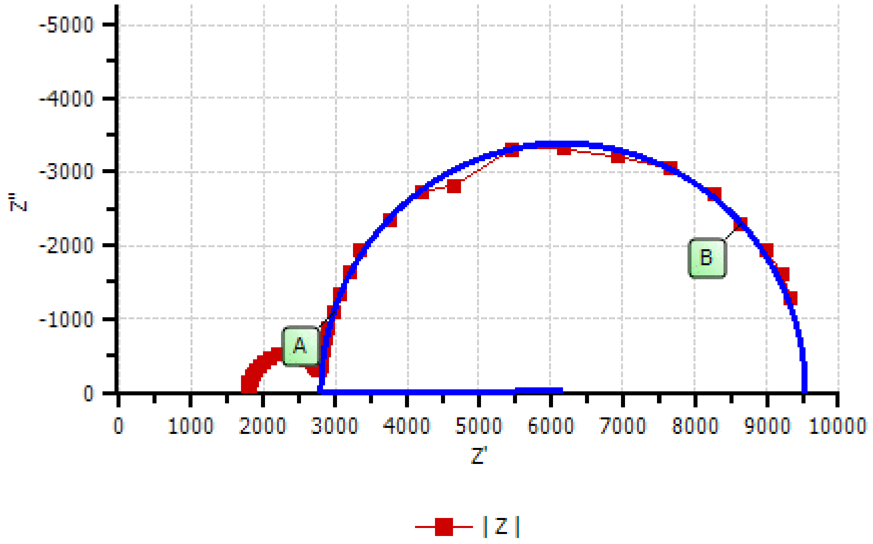
Fit type — The value may change during a calculation, according to the following options:

Fixed	The value remains fixed and does not change during a calculation.
Free	The value can change, either up or down, during a calculation. This is the default option for all Methods except Equivalent Circuit.
Positive	The value can increase during a calculation. This is the default option for the Equivalent Circuit method.
Sub	The value can decrease during a calculation.

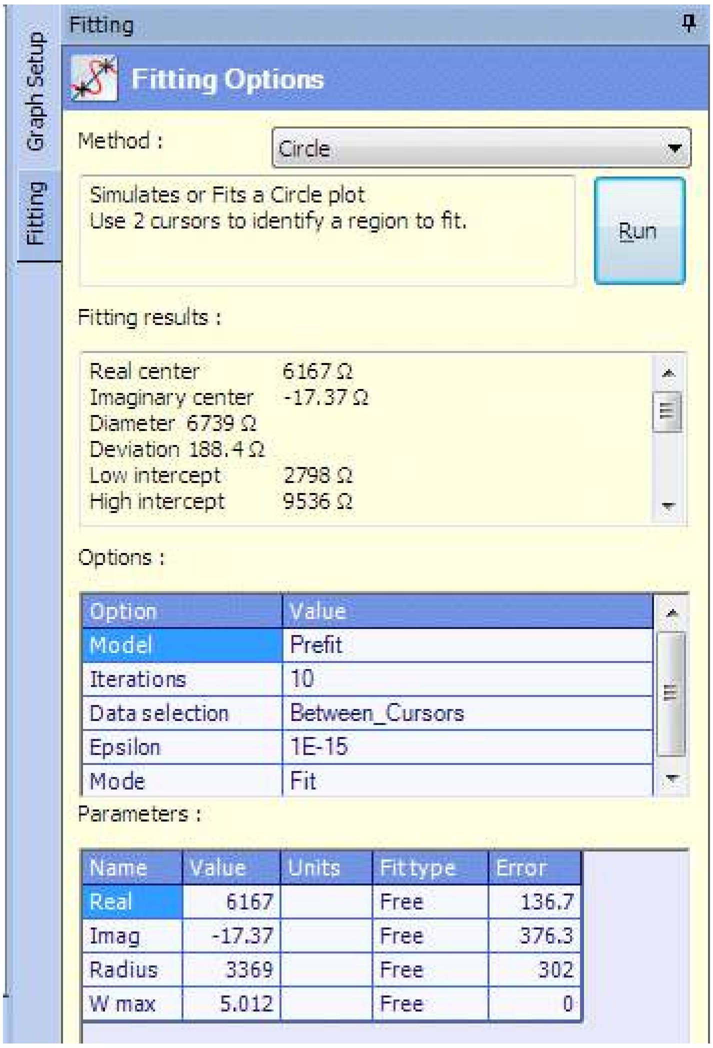
Error — The margin of error associated with the parameter. A small value represents high accuracy.

5.12.2 Circle

The Circle method in the Fitting Options screen fits a circular arc through the data, and is typically used in complex plane plots as follows:



The Fitting Options screen is as follows:



The fields are:

Method

Defines the type of plot, in this case Circle.

Run

This button performs the calculation, and displays the results as a simulated trace on the graph and a set of values in the Fitting Results box.

Fitting Results

When the calculation is performed, this box displays the circle definition as follows:

Real center	The center of the circle, measured on the real (X) axis.
Imaginary center	The center of the circle, measured on the imaginary (Y) axis.
Diameter	The diameter of the circle.
Deviation	The maximum distance of a data point from the circle, in terms of magnitude consisting of both real and imaginary components.
Low intercept	The low point where the circle intercepts the real (X) axis.
High intercept	The high point where the circle intercepts the real (X) axis.
Depression angle	The angle between the real (X) axis and a line drawn from the low intercept to the centre.
ω max	The frequency corresponding to the maximum value of imaginary impedance (the top of the circle). The value is specified in two sets of units, rad/s and Hz.
Estimated Rs	Estimated solution resistance.
Estimated Rp	Estimated polarisation resistance.
Estimated C	Estimated capacitance.

Options

The following options are available:

Model

The model used for the circle definition. The options are:

Normal	Perform an iterative fit, using the current values from the table of parameters as initial values.
Prefit	Draw the circle through three points on the data. This method can be used to obtain initial values of the parameters for a Normal Fit, in case the currently specified values are unsuitable.

Iterations

The maximum number of iterations to be performed during a Normal Fit.

Data selection

This list box selects the range of data through which the line is to be drawn. The options are:

Between Cursors	All the data between two specified points on the graph.
All Points	All the data on the graph, so that there is no need to specify points.

Epsilon

Stop performing iterations of a Normal Fit when the change between iterations is less than this value.

Mode

This list box specifies how the model is applied to the data. The options are:

Fit	Fit the mathematical model to the data and calculate a set of parameters to produce simulated results.
Simulate	Evaluate the model from a set of parameters specified by the user, which may be an approximate representation of a previous fit. This mode only applies to the Normal model, not Prefit.

Parameters

This table contains the following parameters, identified in the Name column:

Real	The real center of the circle, measured on the X axis.
Imag	The imaginary center of the circle, measured on the Y axis.
Radius	The radius of the circle.
W max	The frequency corresponding to the maximum value of imaginary impedance.

For each of these parameters, the remaining columns (Value, Units, Fit Type and Error) are the same as in the Line method.

☞ Line method, Section 5.12.1.

5.12.3 Tafel

This feature is applicable to the ModuLab XM Electrochemical System and has no relevance to materials testing.

5.12.4 Equivalent Circuit

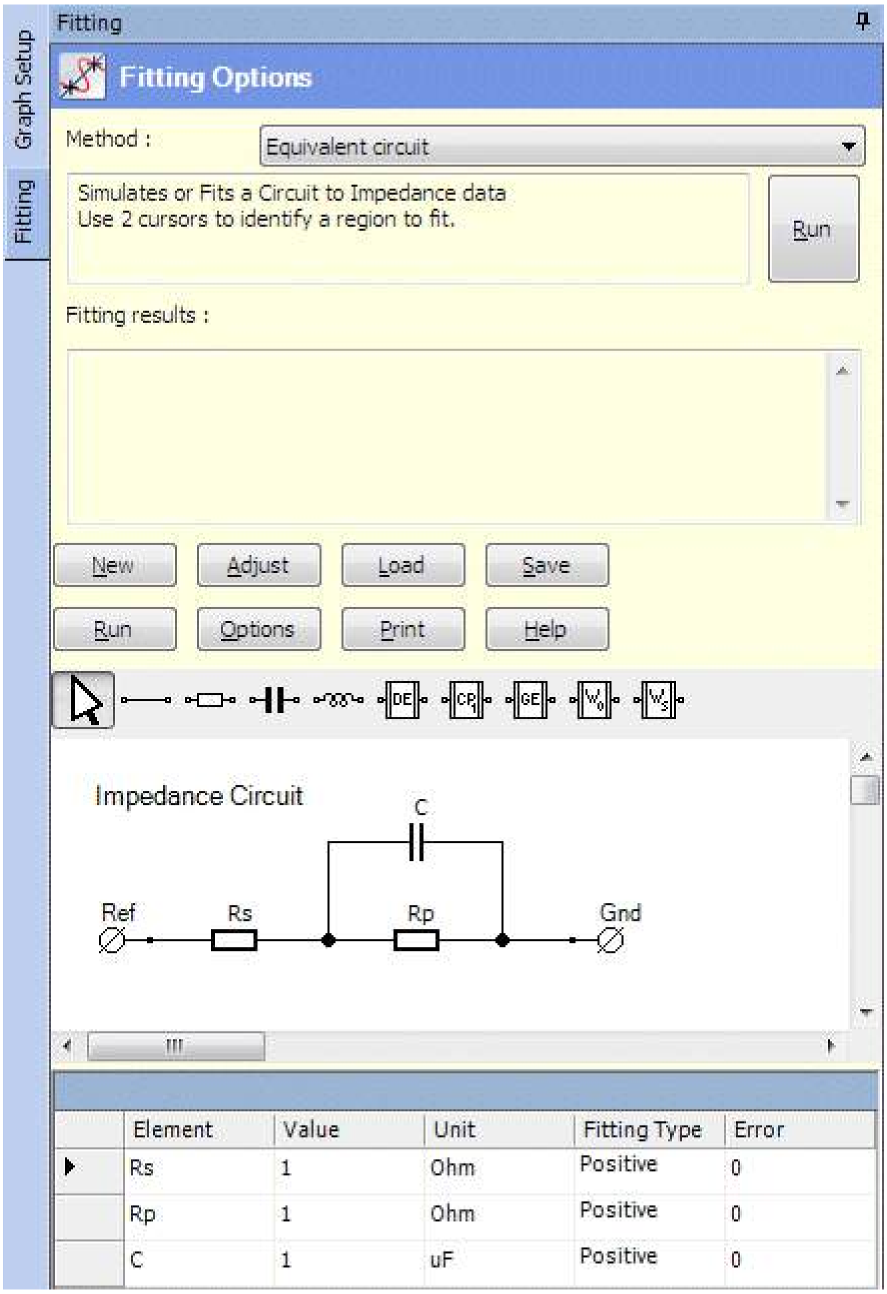
A circuit can be constructed by the user, to represent the electrical properties of the sample, and the values of the components can be calculated in terms of resistance, capacitance and inductance. These calculations are only available for impedance data and cannot be applied to DC *experiments*.

Values that contribute to impedance are calculated, where possible, whenever a curve is fitted to impedance data. For example in the Circle method, the Fitting Results include the following estimated properties:

Rs	Solution resistance.
Rp	Polarisation resistance.
C	Capacitance.

☞ Circle method, Section 5.12.2.

These properties are used in the equivalent circuit in the following Fitting Options screen:



The fields are:

Method

Defines the type of plot, in this case Equivalent Circuit.

Run

This button performs the calculation, and displays the results as a set of values in the Fitting Results box.

☞ Section 5.12.4.5, Running the Equivalent Circuit Calculations.

Fitting Results

Reserved for future use. Not used for the Equivalent Circuit method in this release.

(Buttons)

The two rows of buttons above the drawing space are as follows:

New

Clear the drawing space, ready for building a new circuit.

Adjust

Move the whole circuit, together with the title, to the top left of the drawing space.

Load

Load a previously saved circuit.

Save

Save the current circuit under a specified filename with the .BIN extension.

Run

Run the calculation, same as the Run button at the top of the sub-screen.

☞ Section 5.12.4.5, Running the Equivalent Circuit Calculations.

Options

Display a dialogue box to specify how the calculation is to be performed.

☞ Equivalent Circuit Fitting Options, Section 5.12.4.4.

Print

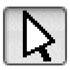
Print the circuit. A print dialogue box will appear.

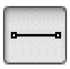
Help

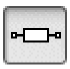
Display help text about this topic.

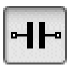
(Toolbar)

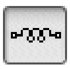
The toolbar above the drawing space has the following buttons:

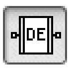
 Select an element of the circuit, for editing.

 Draw a wire.

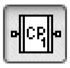
 Insert a resistor.

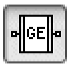
 Insert a capacitor.

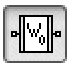
 Insert an inductor.

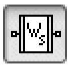


Insert a distributed element.

 Insert a constant phase element.

 Insert a Gerisher element.

 Insert a Warburg open circuit element.

 Insert a Warburg short circuit element.

☞ Specialised Circuit Elements, Section 5.12.4.3.

Circuit Title

This element within the drawing space gives a title for the circuit. A drop-down menu appears when it is right-clicked, with the following options:

Set Font	A font dialogue box appears so that you can specify a font, size, style and colour.
Rename	A text box appears so that you can change the title.

The Circuit Title is a permanent feature of the drawing space and cannot be removed.

Ref

This element within the drawing space represents a reference electrode.

Gnd

This element within the drawing space represents a grounded electrode.

The circuit has to be drawn between the Ref and Gnd elements, so they are permanent features of the drawing space and cannot be removed.

(Element Table)

The Element Table, below the drawing space, has one row for each element in the circuit. The columns are:

Element

The element name. This defaults to an appropriate character or abbreviation followed by a number, but can be changed. For example, if resistors are added to a blank circuit, they will be called R1, R2, etc., but might be renamed to Rs, Rp.

Value

The value of the element, which can be specified by the user or calculated by the system.

Unit

In the case of resistors, capacitors and inductors, this field gives the units in which the element is measured, and they can be changed from a drop-down list box. For all other elements, a dialogue box appears so that the element properties can be specified. These dialogue boxes are also available by right-clicking on the elements in the drawing space and selecting Properties.

Fit Type, Error

These fields are the same as in the Line method.

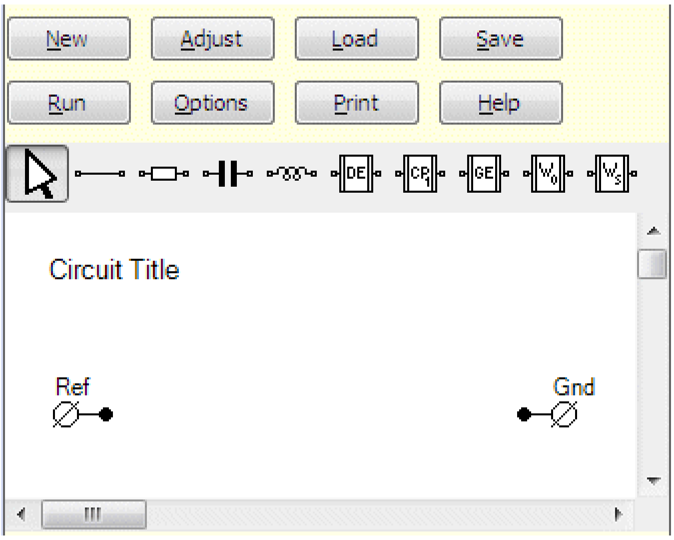
☞ Line method, Section 5.12.1.

5.12.4.1 Drawing a Circuit

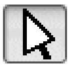
A circuit is drawn by starting with a blank drawing space, containing only the Title and the two permanent elements labelled Ref and Gnd. New elements can be added, including wires to join them up at the intersections which are called Nodes.

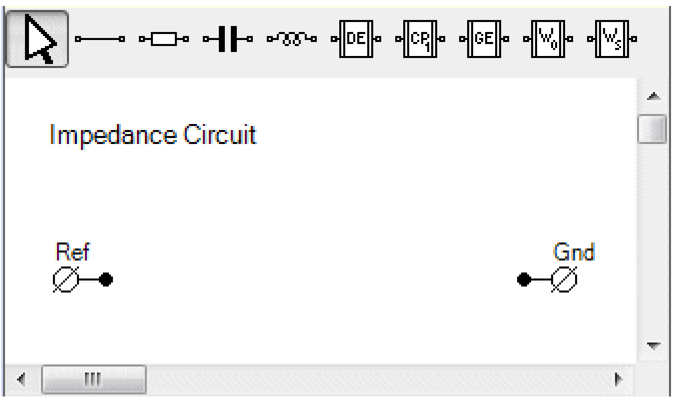
The Fitting Options screen contains a simple circuit containing two resistors and a capacitor. To build this circuit, proceed as follows:

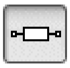
1. Click the New button to clear the drawing space, leaving only the default Title and the Ref and Gnd elements as follows:

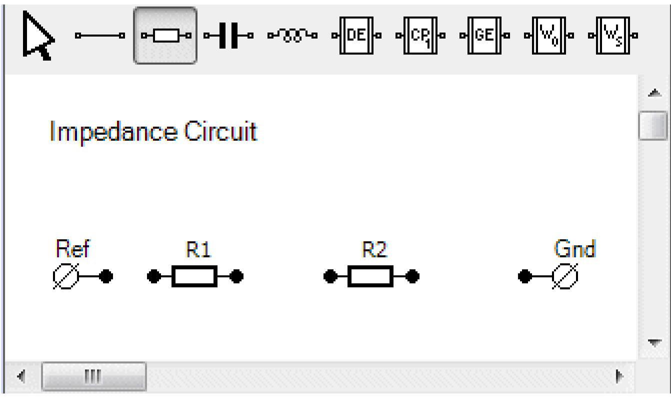


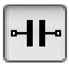
2. Specify a suitable Title for the circuit. This circuit will have an impedance, as a consequence of combining resistance and capacitance elements, so we will call it Impedance Circuit.

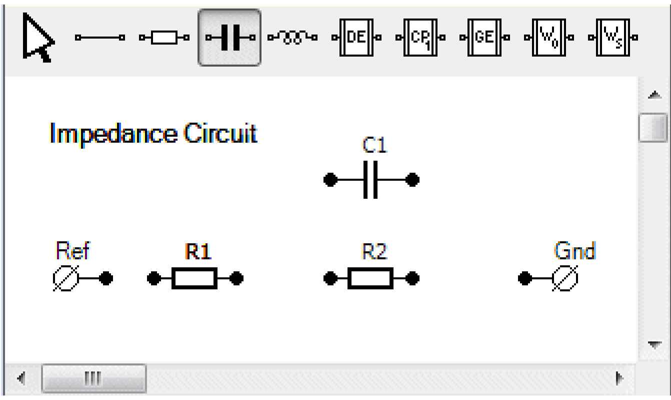
   Click the Selection  toolbar button, then right-click on the Circuit Title element to display the drop-down menu and select Rename to display the title in a text box. Overtype the title, then click anywhere outside the text box to close it. The screen will be as follows:



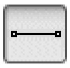
3. Click on the Resistor  toolbar button, then click on the drawing space to the right of the Ref element, to insert a resistor labelled R1. Click again to the right of R1 to insert a second resistor labelled R2, so that the screen is as follows:

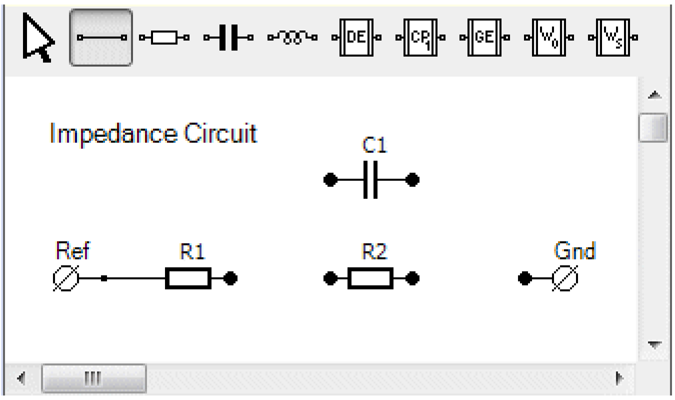


4. Click on the Capacitor  toolbar button, then click on the drawing space above the resistor R2 to insert a capacitor C1 as follows:

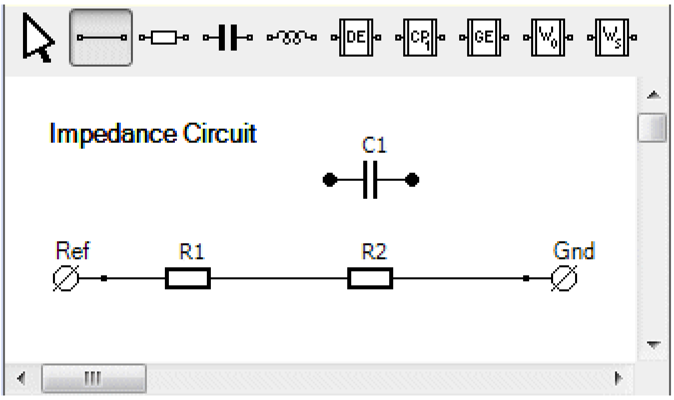


We will now see how to join up the elements, and the letter N will appear whenever the cursor is over a node.

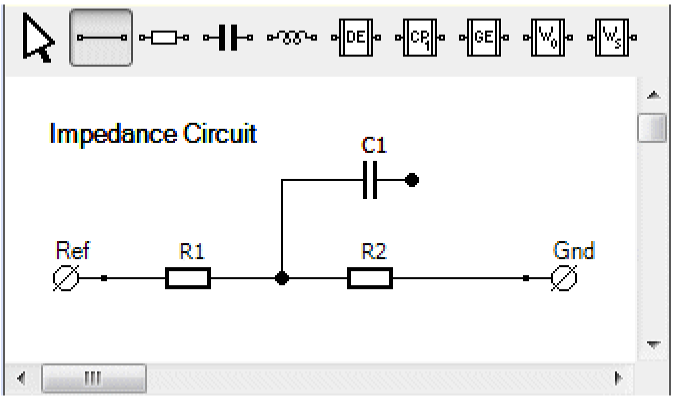
5. Click on the Wire  toolbar button, then position the cursor over the node to the right of the Ref element, so that the letter N appears, and click the node. Then move the cursor to the right, so that the letter N disappears, and position it over the node to the left of the R1 element and the letter N will re-appear. Click on the node so that the two elements become joined up as follows:



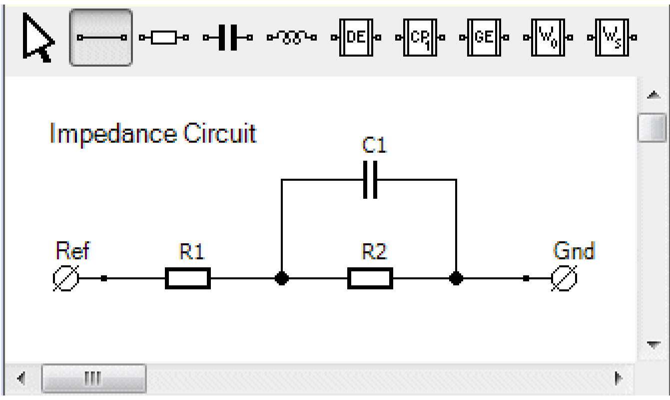
6. Similarly, click the two nodes between R1 and R2, and the two nodes between R2 and Gnd, so that they become joined up as follows:



7. Hold the cursor over the wire between R1 and R2 so that the letter W appears, then click on the wire to create a new node, and the letter W will change to N. Then move the cursor vertically upwards and click in the space to the left of C1 (but not on the node), to create a corner. Then move the cursor to the right and click on the node to the left of C1 so that the screen becomes as follows:

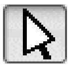


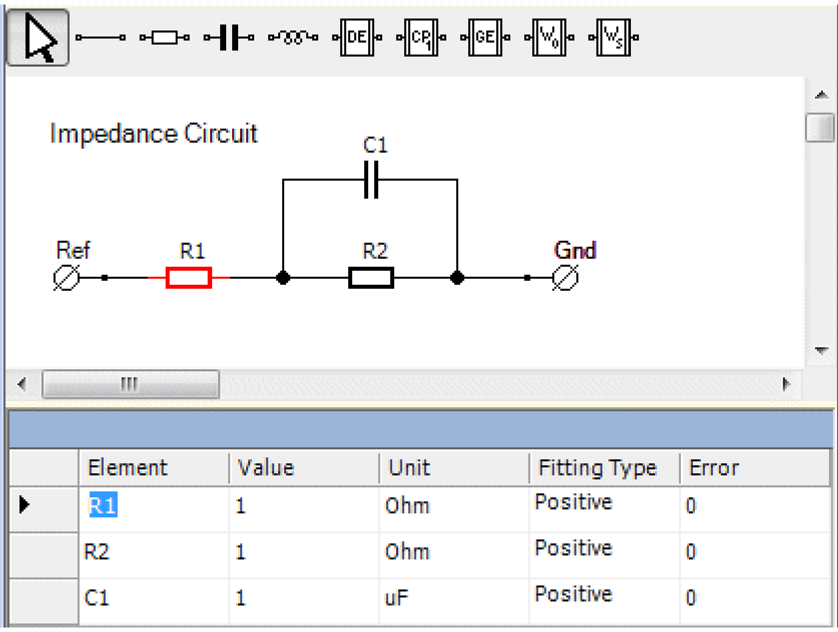
8. Similarly, click on the node to the right of C1, then move the cursor to the right and click to create a corner. Then move the cursor down to the wire between R2 and Gnd, so that the letter W appears, then click to create a new node and the screen will be as follows:



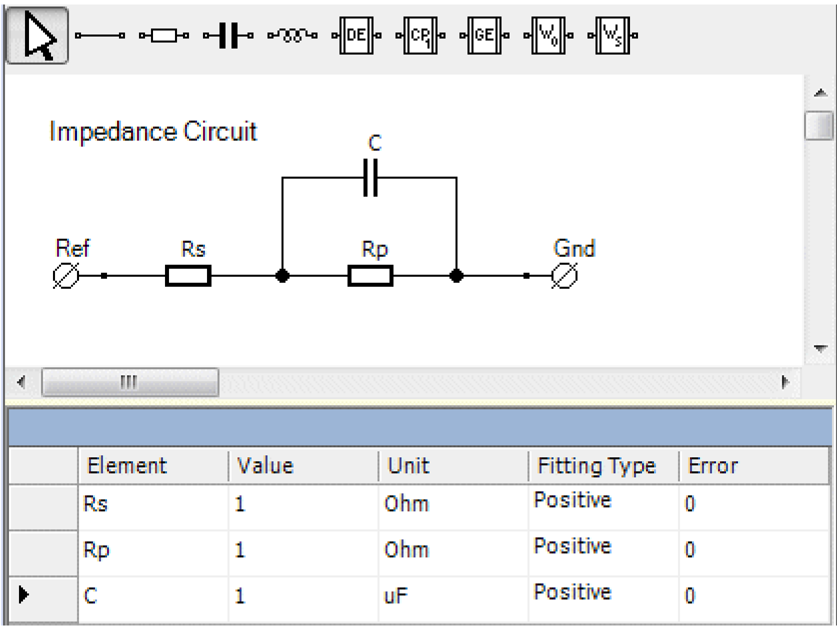
NOTE: The small dot to the left of Gnd is part of the element, and it's already joined to a wire, so you can't click on it. You need to click on the wire.

9. Finally, the labels need to be changed to represent the required component names.

   Click on the Selection  toolbar button, then right-click on R1 and select Rename from the drop-down menu. The element will turn red and the cursor will jump to the label in the element table as follows:



10. Overtype the label in the element table with the appropriate name, for example Rs, then click on the drawing space to complete the edit. The new name will appear over the resistor, and the element will turn black. Similarly, change the other element names so that R2 becomes Rp and C1 becomes C. If you like, after overtyping R1, you can click directly on R2 in the element table and this will complete the edit of R1 and start the edit of R2, so that R1 turns black and R2 turns red. Then you can move directly to C1 and when editing is complete you can finish by clicking on the drawing space. The screen will be as follows:

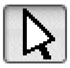


5.12.4.2 Circuit Editing

The following actions are available when drawing and editing a circuit.

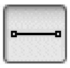
Move an Element

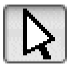
All elements, including the permanent elements (Circuit Title, Ref and Gnd) can be moved to appropriate positions as follows:

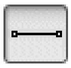
1. Click the Selection  button, then do either of the following:
   - Click on a single element to be moved.
   - Click on an empty drawing space and drag the cursor to select multiple elements.
2. Drag the element(s) across the drawing space. An element can be moved along a wire to which it is attached, but if it is moved perpendicular to a wire, the wire will move so that it remains attached to the element. Any other elements attached to the wire will also move, and the movement will be perpetuated throughout the diagram, as far as is necessary to keep all the connections in place.

Join Elements

All elements must be joined up using wires, otherwise the calculations cannot be performed and the elements cannot be given values. Elements are joined as follows:

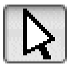
1. Click the Wire  button on the toolbar, then click the nodes on the adjacent elements. If the drawing space is clicked between nodes, it will create a corner. When the elements are joined, the nodes will disappear leaving a continuous line between the elements. However, a node will remain visible if the end point of a wire is joined to the middle of another wire, away from its end points. In this case, to achieve a closed-up joint, the node has to be held over the wire so that the N label changes to W, then you can click the node and it will change back to N and the joint will be closed.

2. To check that all the joints are closed, click the Selection  button on the toolbar and attempt to move the elements. If the elements are joined, the wires will move with the elements, creating corners as required, but will not open up any gaps.

   If any gaps open up, you will need to select the wire  button and close them.

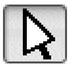
Rotate Element

All elements that contribute to impedance (everything except Title, Ref, Gnd and wires), can be rotated so that they are horizontal or vertical, but only if they are on their own, not connected to anything.

1. Click the Selection  button on the toolbar, then right click the element to display the drop down menu and click Rotate. This is a toggle action, so the element will change from horizontal to vertical and vice-versa.

Rename Element

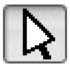
All elements can be renamed, except Ref, Gnd, and the wires which have no names.

1. Click the Selection  button on the toolbar, then right click the element to display the drop down menu and click Rename. The cursor will jump to the Element Table so you can overtype the name. Alternatively you can go straight to the element table and edit the name without using the drop-down menu.

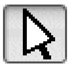
   When editing the Title, which does not appear in the element table, you have to right-click the element and display the drop-down menu, then select Rename and a text box will appear so you can overtype the text.

Delete Element

All elements can be deleted, except Title, Ref and Gnd.

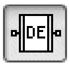
1. Click the Selection  button, then do either of the following:
    - Hold the cursor over a single element so that it turns red.
    - Click on an empty drawing space and drag the cursor across multiple elements, so that they all turn red.
2. Press the Delete key on the keyboard to delete the highlighted element(s).

Alternatively, to delete an element that contributes to impedance (resistors, capacitors etc.):

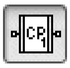
1. Click the Selection  button.
2. Right-click on the element, then select Delete from the drop-down menu.

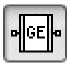
5.12.4.3 Specialised Circuit Elements

The Equivalent Circuit toolbar contains the following specialised elements:

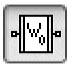


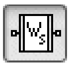
Distributed element


Constant phase element



Gerisher element


Warburg open circuit element


Warburg short circuit element

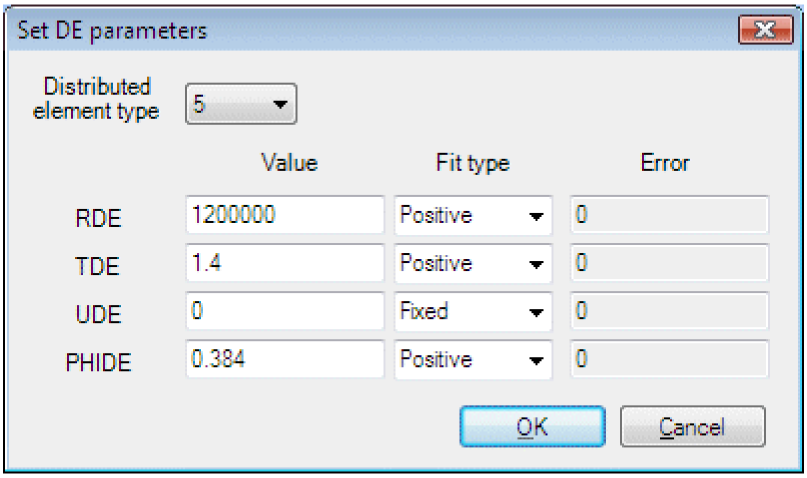
These elements are complete self-contained circuits, each representing an impedance, in accordance with a combination of resistance, capacitance and inductance, and they can be combined with other elements to create larger circuits. These elements are normally used for specific applications, and are described in the LEVM Manual.

☞ LEVM Manual (J. Ross Macdonald and Solartron Group Ltd), available on the Solartron website:
www.solartronanalytical.com/downloads/software/levm_manual.pdf

Each of these elements has a Parameters dialogue box which can be displayed using either of the following methods:

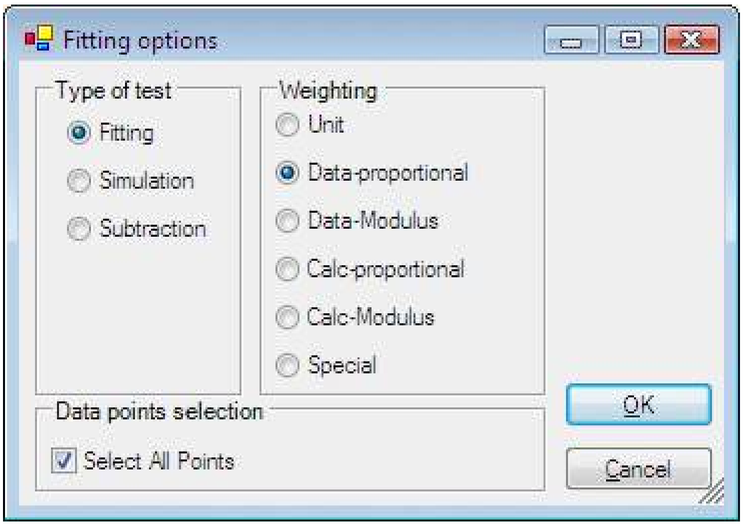
- Right-click on the element to display the drop-down list box and click Properties.
- Select the Unit field in the Element Table below the drawing space, then click on the field again.

The appropriate dialogue box will appear. For example, in the case of a DE element it will be as follows:



5.12.4.4 Equivalent Circuit Fitting Options

When you click the Options button above the Equivalent Circuit toolbar, the following dialogue box appears:



The fields are:

Type of test

This set of radio buttons specifies how the circuit, with calculated values of the components, is fitted to the data. The options are:

Fitting	Fit the circuit to the data and calculate a set of component values to produce simulated results.
Simulation	Evaluate the circuit from a set of component values specified by the user, which may be an approximate representation of a previous fit.
Subtraction	Produce a simulated set of data, then subtract it from the real data and plot the result.

Weighting

Unit	No weighting.
Data-proportional	Uncertainty of the real and imaginary components of the data is proportional to their magnitudes.
Data-Modulus	Uncertainty of the real and imaginary components of the data is proportional to their modulus (square root of sum of squares of real and imaginary components).
Calc-proportional	Same as Data-proportional, but based on model calculations.
Calc-Modulus	Same as Data-modulus, but based on model calculations.
Special	Special FRA weighting.

Further details of weighting are in the LEVM manual.

☞ LEVM Manual (J. Ross Macdonald and Solartron Group Ltd), available on the Solartron website:

www.solartronanalytical.com/downloads/software/levm_manual.pdf

Select All Points

If this box is checked, all the data points are used for fitting, otherwise the data points defined by the cursors are used.

5.12.4.5 Running the Equivalent Circuit Calculations

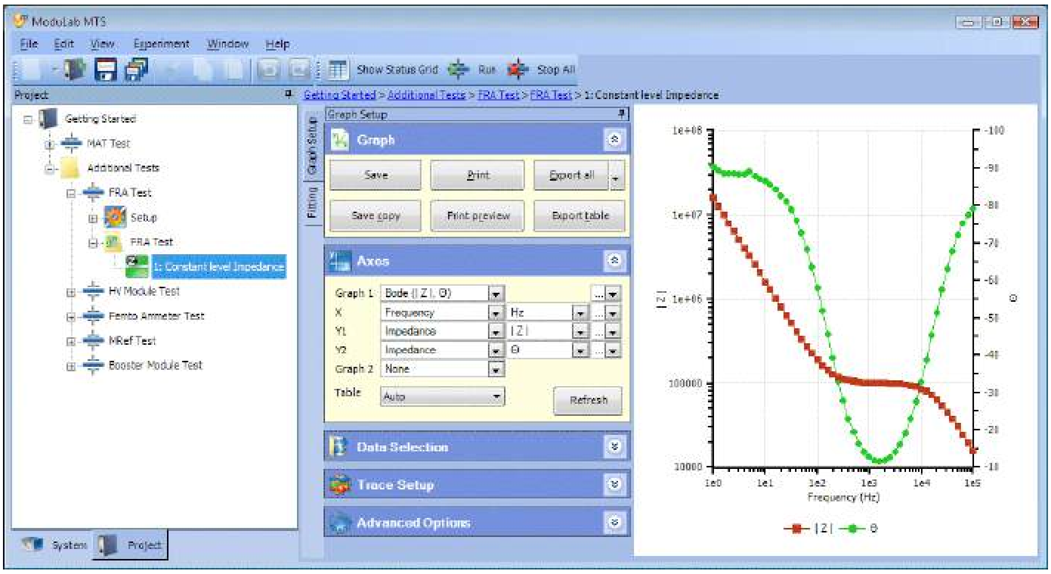
Equivalent circuit calculations can only be performed if you have set up a circuit with the appropriate elements, to match the characteristics of the sample and the data it is likely to produce. The correct design of a circuit may therefore be a matter of trial and error, until you find something that works.

An example circuit is provided to represent the Test Circuit in the dielectric reference module, and it can be used to fit a pair of curves to the impedance and phase angle traces of a Bode plot. To use this example, you need a materials core module and a frequency response analyzer, and you should have completed the Frequency Response Analyzer Test using the Getting Started project during the Installation Tests.

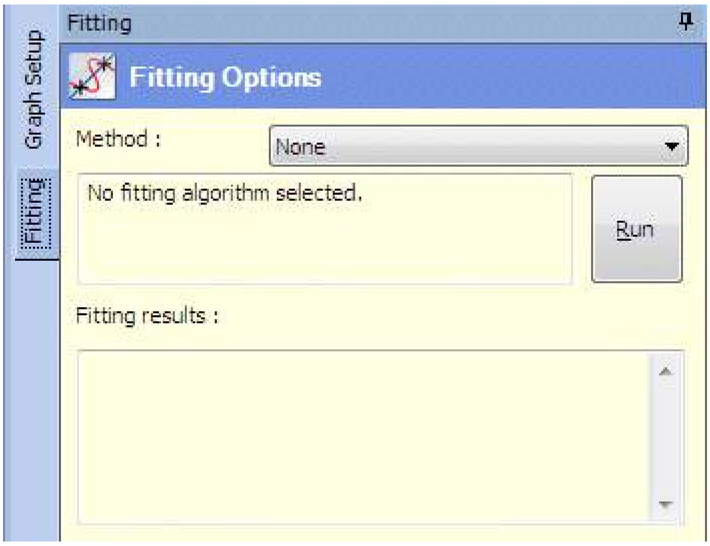
☞ ModuLab XM Installation Guide

To use the example circuit, proceed as follows:

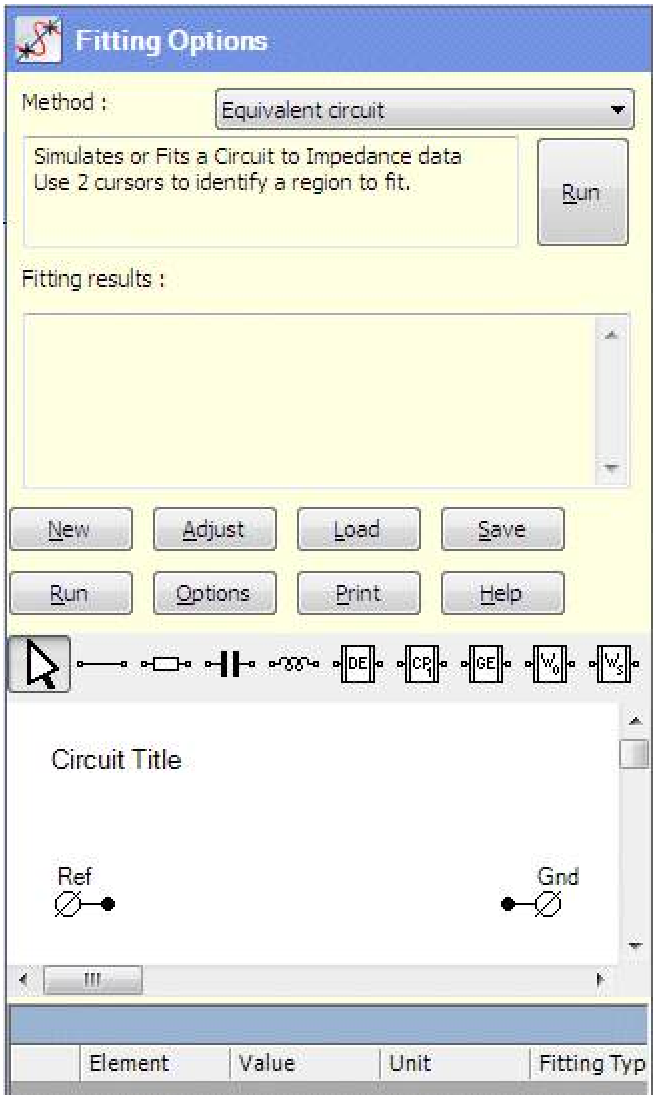
1. Open the Getting Started project and expand the Additional Tests item in the left-hand navigation panel, then open the FRA Test *experiment* folder, then the FRA Test data folder, and click on Constant Level Impedance. This will display the data in the default format for the *step*, normally a Bode plot of impedance magnitude and phase angle against frequency.
2. If any other format is displayed, change the Graph 1 field in the Axes sub-screen to Bode (|Z|, θ) to display the data as follows:



3. Click the Fitting tab at the top left of the central column of sub-screens to display the Fitting Options as follows:



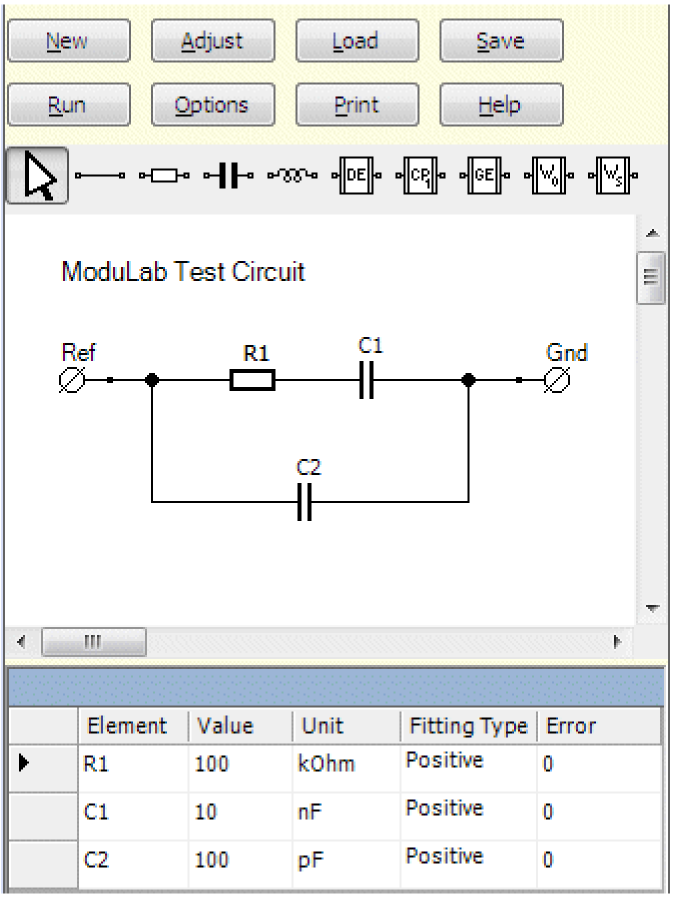
4. In the Method field, select Equivalent Circuit to display a blank circuit display panel and the control buttons as follows:



5. Click the Load button to display a filing system dialogue box with a list of Fitting Models. The system will go to the folder that was used last time a file was loaded, but initially it will be:

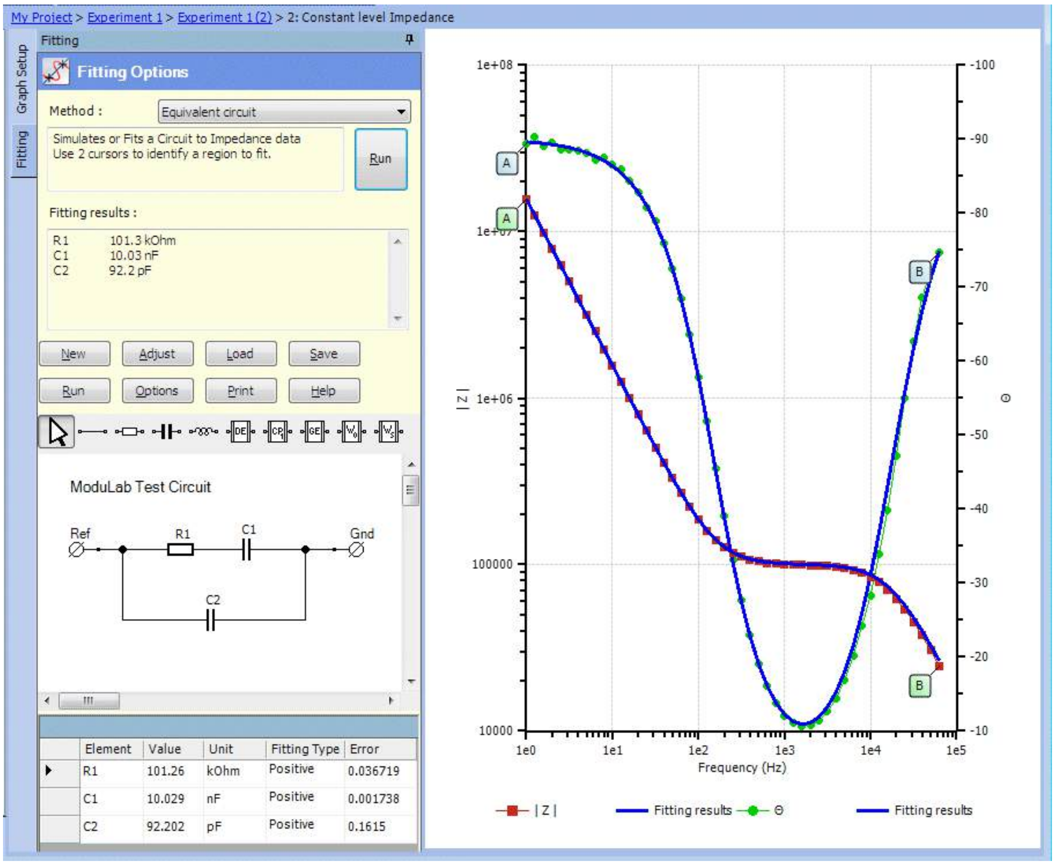
   C:\My Data\ModuLab\Fitting Models\

6. Select the model file ModuLab TestCircuit.bin and click the Open button to display the circuit as follows:



7. If you want to specify a section of the data for fitting, click on either of the curves on the Bode plot to add the points A and B. Alternatively, if you want to apply fitting to the entire data, do not add any points.

8. Click the Run button (the one above the circuit, or the one at the top of the Fitting Options sub-screen), to display the fitting results as follows:



The results have appeared as traces on the graph, and in the tabulated list under the circuit. In this example, the points A and B are at the ends of the curves, but they can be moved and you can click the Run button again to obtain new fitting results.

5.13 REPORTS

A *report* is a document describing an *experiment*, which can be opened in a word processor for editing and printing. The document may contain *experiment* settings and results, including connection diagrams, graphs, tables and user comments.

The *data* displayed in a *report* is based on the graph files associated with the *experiments*. These are generated when an *experiment* is run and the graphic and tabulated results are appropriately configured for display, and the Save or Save Copy buttons are clicked in the Graph sub-screen. Alternatively, graph files can be generated independently of an *experiment* and the *data* can be added.

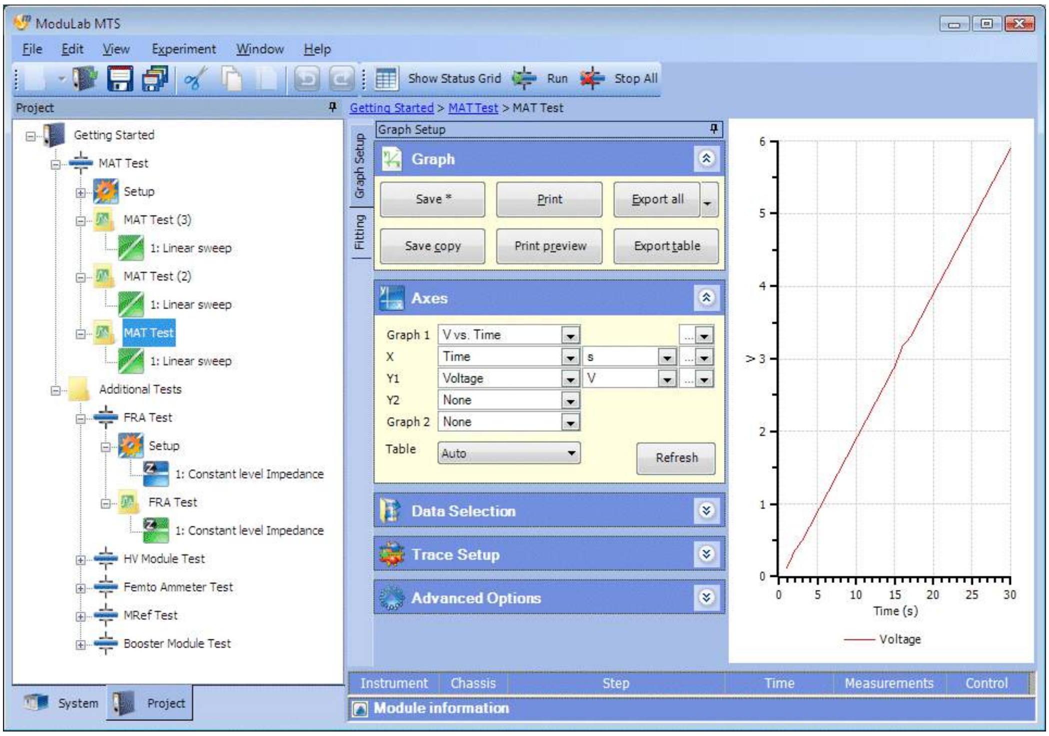
☞ Data, Graph and Graph File, Sections 5.10, 5.10.1 and 0.

A *report* can be generated in a *project*, *experiment* or general-purpose *folder*, and in each case there will be a *report folder* at the appropriate position in the navigation tree. This may contain any number of RTF document files, each with a specified filename, referencing a list of graph files. The list will default to all the graph files in the same structure as the *report folder*, at the same level, but other files can be added.

Here is an example which uses *data* from the Getting Started project, where the MAT Test has been performed three times and the FRA Test has been performed once. To follow this example, you need to have performed the MAT Test and one of the Additional Tests at least once.

To create the report:

1. Open the Getting Started project and expand the *experiment* structures in the left-hand navigation panel, for the MAT Test and one of the additional tests (in this case the FRA Test), and click on the *data* folder for the MAT Test, so that the screen is as follows:

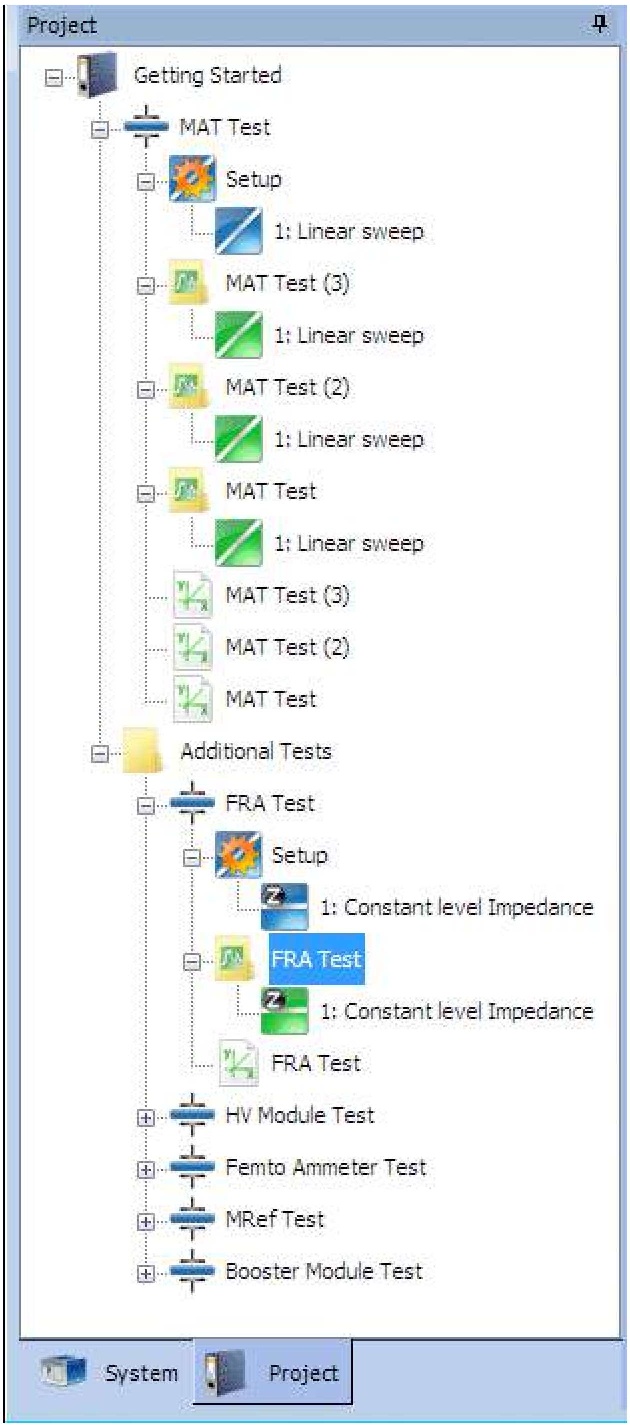


2. Click the Save button in the Graph sub-screen to save the contents of the MAT Test data folder as a graph file, which will appear at the bottom of the experiment structure.

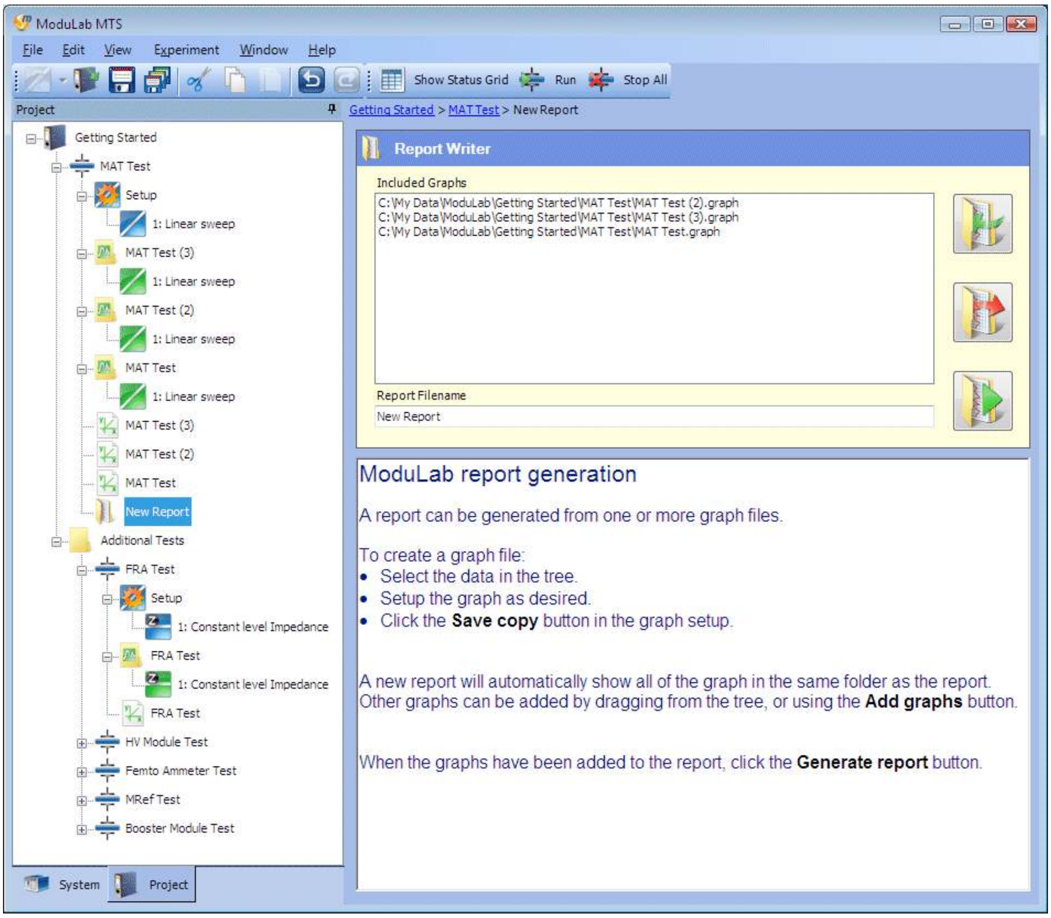
3. If the MAT Test has been run more than once, select the appropriate *data* folders, for example MAT Test (2) and MAT Test (3), and in each case click the Save button in the Graph sub-screen to add a graph file.

4. In the structure under the Additional Tests folder, select a *data* folder for any *experiment* that has been run, for example FRA Test, and click the Save button in the Graph sub-screen to add a graph file.

A screen showing three graph files for the MAT Test and one graph file for the FRA Test is as follows:



5. Right-click on the *experiment* item for the MAT Test to display the drop-down menu and click on Add New, then Report. A report folder called New Report will appear in the navigation panel, under the graph files, and the pathnames of the graph files will appear in the Report Writer sub-screen, in the list of Included Graphs, as follows:



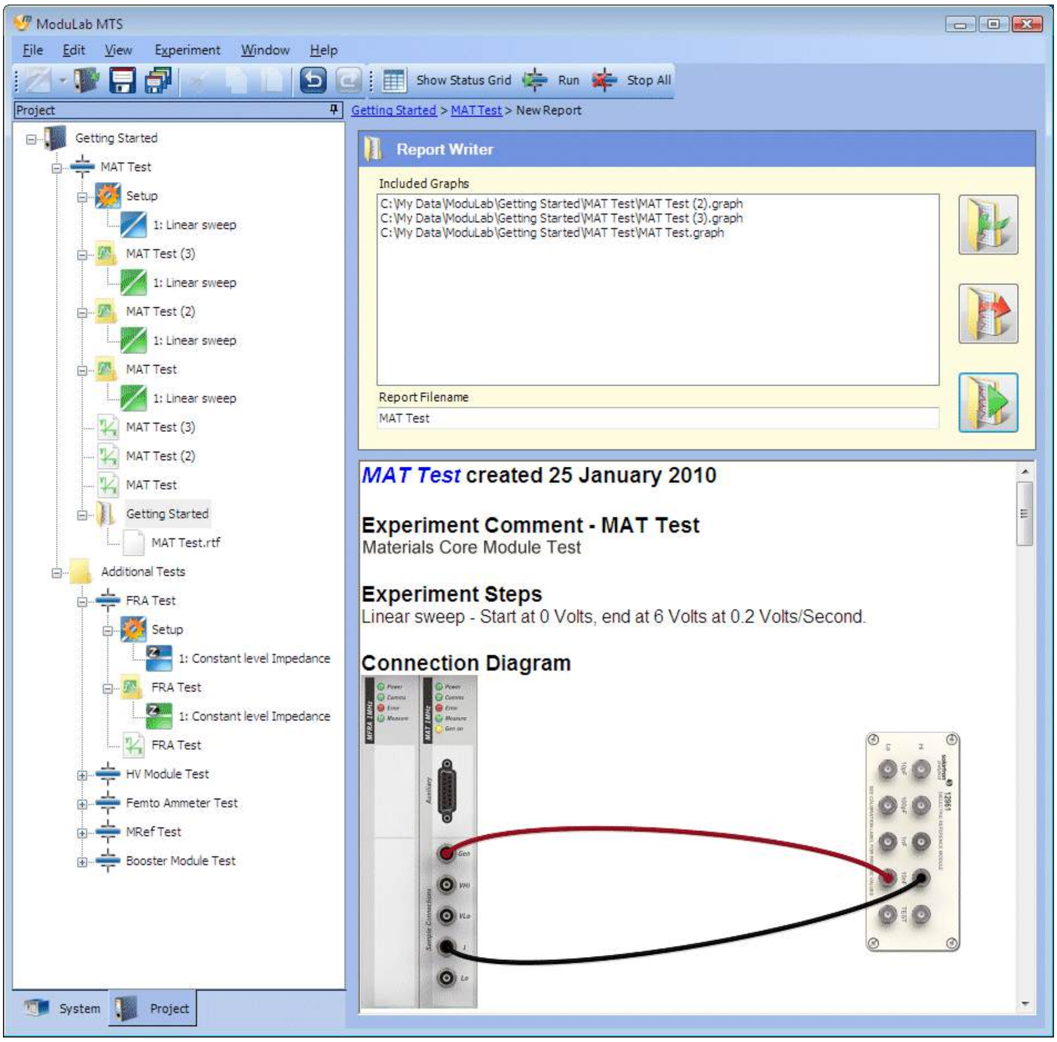
Only the graph files for the MAT Test have been listed, not the graph file for the FRA Test, because it is in a different part of the structure.

The lower panel gives a brief description of how to generate a *report*.

6. Rename the New Report folder in the navigation panel to something more suitable, for example Getting Started.

7. Type a suitable name in the Report Filename field, in the Report Writer sub-screen, for example MAT Test.

8.  Click the Generate Report button, to the right of the Report Filename field, to create an RTF file with the specified name in the *report folder*, and display the contents of the *report* in the lower panel as follows:



9. Scroll down the lower panel to view the complete *report*.

The *report* contains the report date, and then the following information from each successive graph file in the upper panel.

- An *experiment* comment, from the Comments sub-screen in the *experiment* setup screen.

  ☞ Section 5.3.1.

- A list of *steps* within the *experiment*, and the excitation waveforms from the associated Scan Setup screens.

  ☞ Section 5.8.4.

- A connection diagram.
- A list of equipment items used in the *experiment*, including the core module and optional modules.

- The graphs associated with the *experiment*, according to the formatting that has been applied to the results.

  ☞ Data, Section 5.10.

- The tabulated data associated with the *experiment*, according to the formatting that has been applied to the results.

  ☞ Data, Section 5.10.

- Data file comments, from the Comment field in the Start Experiment screen.

  ☞ Section 5.2.2.

- Fitting results.

  ☞ Section 5.12.

At the bottom of the display, at the end of the data from the last graph file, there is a list of files that make up the *report*, beginning with the RTF file that represents the document, followed by all the associated graph files.

NOTE: It is also possible to add a *report folder* by selecting New Report from the drop-down menu, instead of Add New, then Report. However, if a general-purpose *folder* under the *experiment* is selected, the *report folder* will be added directly under the *experiment*, outside of the *folder*.

☞ Add New in the File menu (Section 2.4.1) and New Report in the Experiment menu (Section 2.4.4).

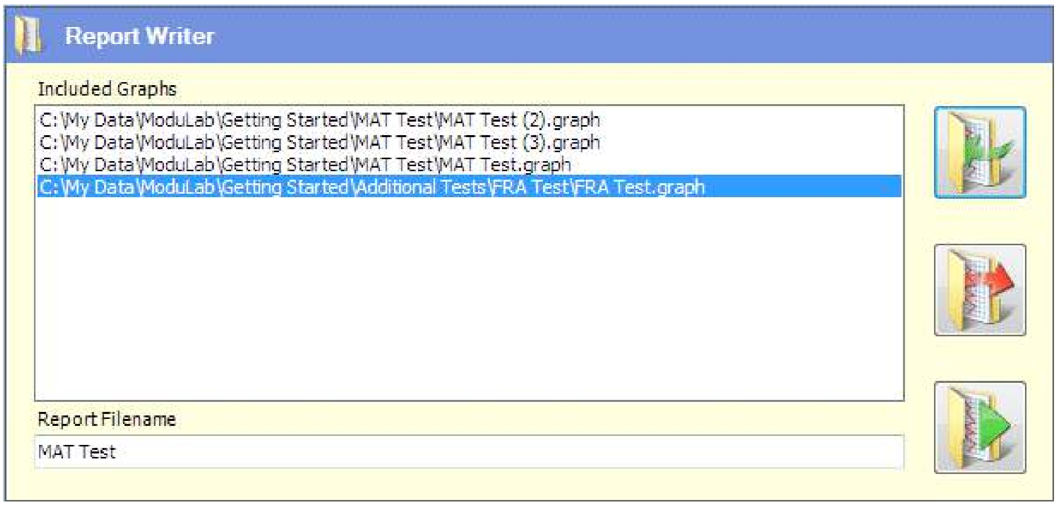
5.13.1 Add Data to Report

When a new *report folder* is added to the *data* structure in a project, the Report Writer will automatically contain all the graph files within the same part of the structure, at the same level. The example in the previous section showed how to create a report that would include three graph files from the MAT Test, but the graph file for the FRA Test was missed out because it was in a different part of the structure. To continue this example and add the FRA Test to the list of Included Graphs, proceed as follows:

1.  Click the Add Graphs button, in the Report Writer sub-screen, to display a filing system dialogue box, listing the *data* files and graph files associated with the MAT Test. Navigate upwards one level and open the Additional Tests folder, then the FRA Test *experiment*, then the FRA Test.graph file. The file will appear in the Report Writer, in the list of Included Graphs.

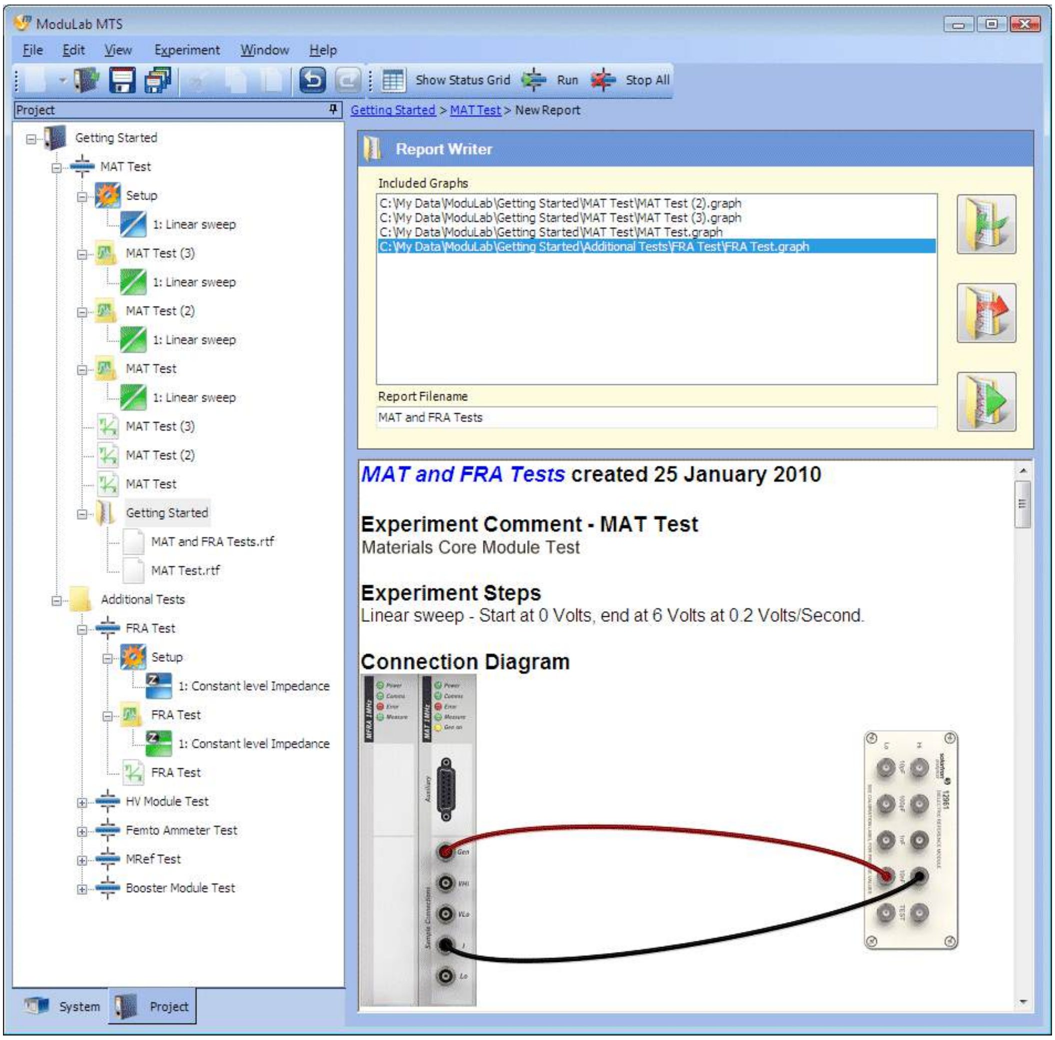
   Alternatively, drag and drop the graph file from the left-hand navigation panel to the list of Included Graphs (but make sure you hold down the mouse button, because if you click and release, the Graph Setup screen will appear).

   The Report Writer sub-screen, after addition of the FRA Test, will be as follows:



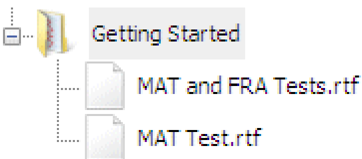
2. Change the Report Filename field to something more suitable, for example MAT and FRA Tests.

3.  Click the Generate Report button, to the right of the Report Filename field, to create an RTF file with the specified name in the *report folder*, and display the contents of the *report* in the lower panel as follows:



Scroll down and review the report, and you will find that it contains the results of the three MAT Tests, followed by the FRA test.

The report will remain on display only temporarily, until you click another item in the navigation panel. To redisplay the report, you need to click on the appropriate RTF file under the Getting Started *report folder*. There are currently two of them (as a consequence of choosing a new name for the report to include the FRA test), as follows:



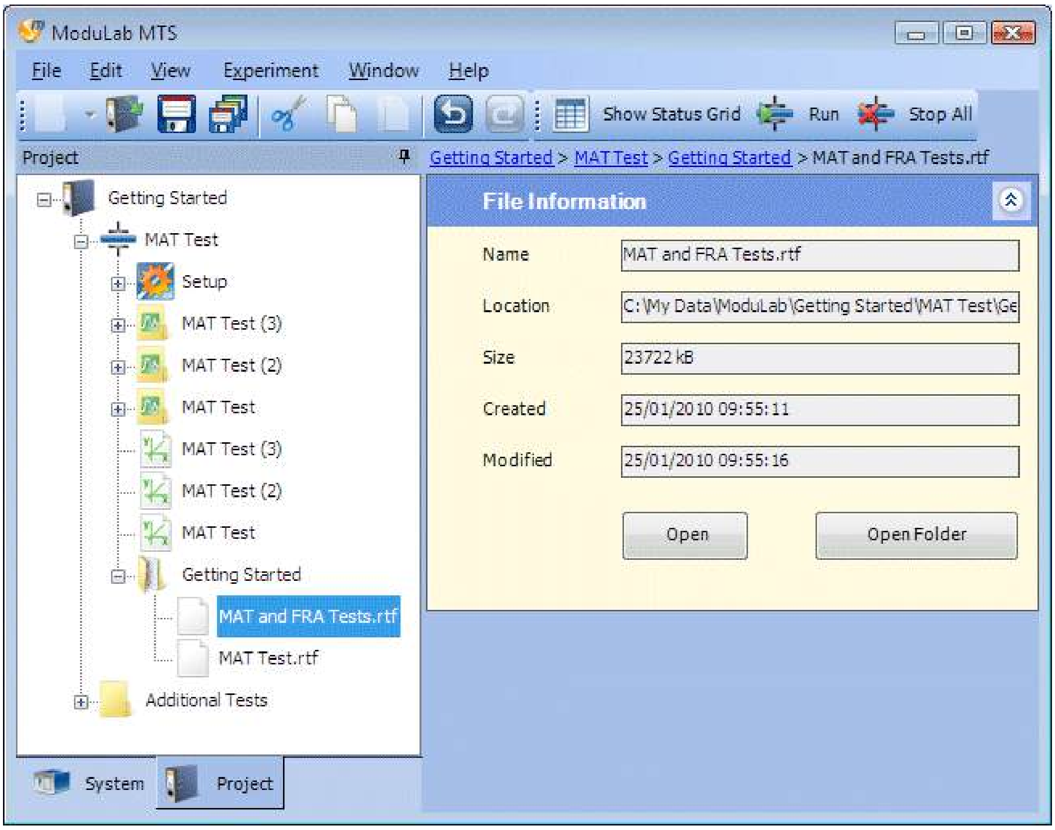
4. If you want to redisplay the contents of the one of these reports, proceed as described in the next section.

5.13.2 Open Report

A *report* can be opened using any Windows application that supports the RTF file format, for example word-processing programs, then you can view and process the report, using the features of the program, such as editing and printing.

To open a *report*, proceed as follows:

1. In the left-hand navigation panel, expand the *report folder* and click on the RTF file. The File Information screen will appear as follows:



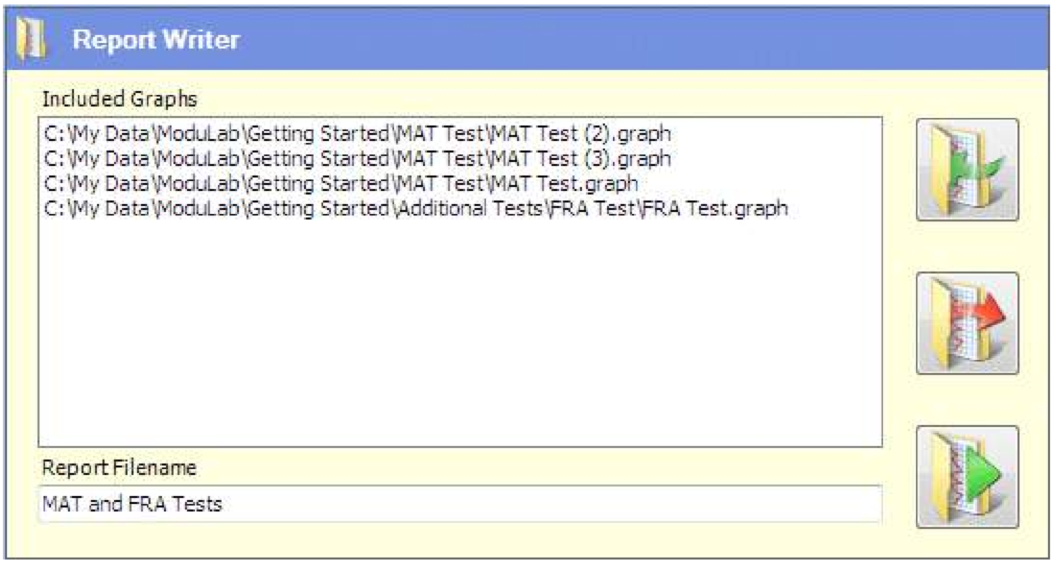
☞ The fields in this screen are described in Section 5.14.

2. Click the Open button to open the *report* file in the default application on your computer that uses the RTF file extension. Alternatively, click the Open Folder button to open the Windows filing system folder where the file is located, then use the standard Windows features to open the file in any application that uses the RTF format.

3. Use the features of the application to do whatever you want with the report, for example editing and printing.

5.13.3 Report Writer

The Report Writer sub-screen, which appears when a *report folder* is selected from the navigation panel, is as follows:



The fields and buttons are:

Included Graphs

This field contains the full pathnames of all the graph files to be included in the *report*. The list defaults to all the graph files in the navigation tree, alongside the *report folder* at the same level. Files can be added to the list using the Add Graphs button (see the list of buttons below), or by dragging the graph items from the left-hand navigation panel. They can be removed from the list using the Remove Graphs button.

Report Filename

This field contains the filename (without the RTF extension) for the document that is generated when the *report* is run. The filename defaults to the *report folder* in the left-hand navigation panel, but you can change it. There is no need to specify the extension as this will be added automatically. The *report* can be run using the Generate Report button (see the list of buttons below).

Add Graphs

Click this button to add a graph to the list of Included Graphs. A dialogue box will open so that you can browse the filing system and select any file with the GRAPH extension.

Remove Graphs

Select a graph, or any number of graphs, from the list of Included Graphs, then click this button to remove them from the list.

Generate Report

Click this button to generate a *report* from the list of Included Graphs. The *report* will appear in the lower window, and an RTF file will be created in the *report folder*, based on the specified Report Filename.

5.14 FILE INFORMATION

The files that are used by ModuLab XM are stored in the directory structure that appears in the filing system browser window when a *project* is opened.

☞ Introduction to the User Interface, Section 2.1, and Open Project from the File menu, Section 2.4.1.

ModuLab XM interprets the files within this directory structure (particularly those with the INFO and DATA extensions), to build the structure of items in the left-hand navigation panel and display the screens in the right-hand window. The item names in the navigation panel are based on the filenames, but do not display the extensions.

If a file exists within the structure, that is not used by ModuLab XM, or has been created by ModuLab XM for use with other applications, it will appear in the navigation panel with the file extension. This will include the following:

- CSV files containing tabulated lists of results. These can be created using Export Table or Export All from the Graph sub-screen, and can be opened from spreadsheet applications.

  ☞ Graph, Section 5.10.1.

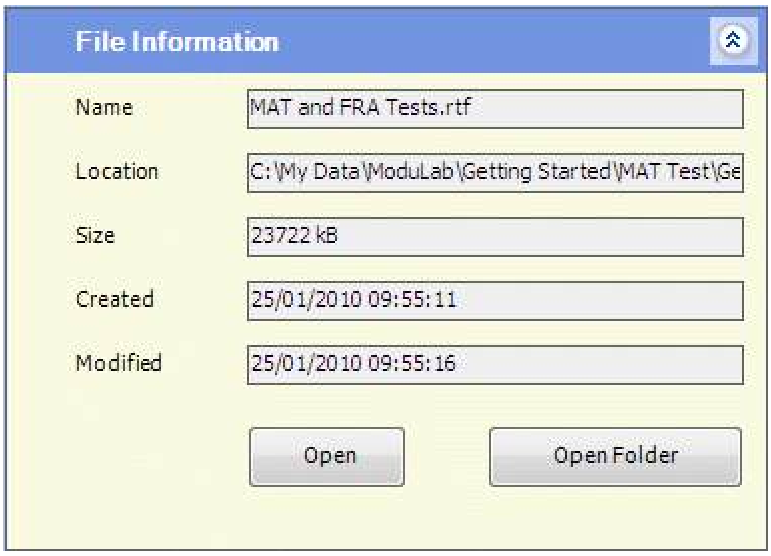
- RTF files containing *reports*. These can be created using the Report Writer.

  ☞ Reports, Section 5.13, and Report Writer, Section 5.13.3.

- Z files for use with Zplot, for displaying exported data.
- COR files for use with Corrware, for displaying exported data.

  ☞ Data can be exported to Zplot and Corrware from the Export All button in the Graph sub-screen, Section 5.10.1.

If you click on a file in the navigation panel that displays an extension, for example a *report* file, the File Information screen will appear as follows:



This screen gives information about the file, and you can open it from other applications using the Open or Open Folder buttons. The fields and buttons are as follows:

Name

The filename, including the extension.

Location

The directory path where the file is located.

Browse

This button appears only if the File Information screen represents a shortcut folder, and enables you to browse the filing system and locate a folder.

☞ Shortcut Folder, Section 5.14.1.

Size

The size of the file.

Created

The date and time when the file was created.

Modified

The date and time when the file was last modified.

Open

This button opens the file in the default application on your computer that uses the specified extension.

Open Folder

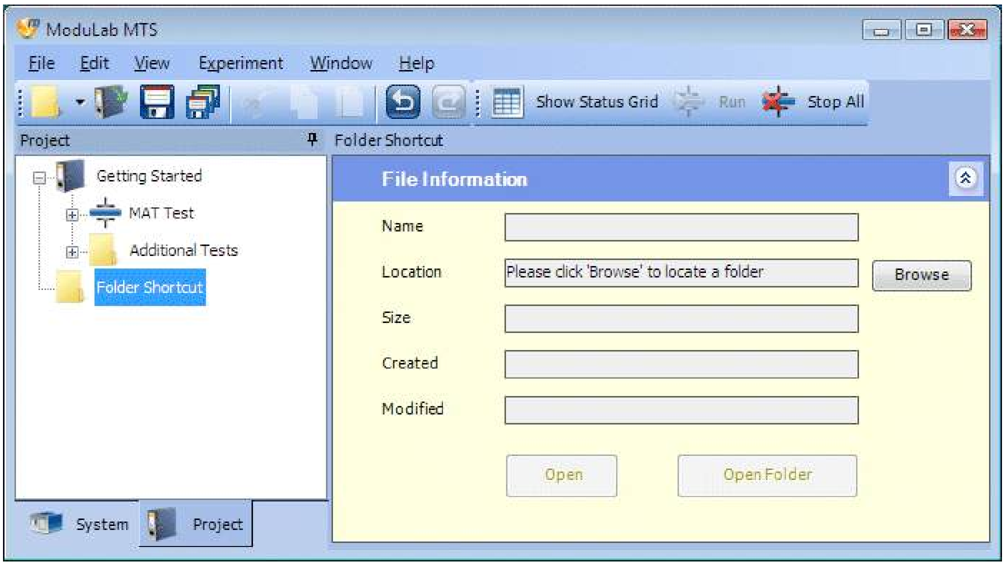
This button opens the Windows filing system folder where the file is located. The file can then be opened in any application that supports the appropriate file format, according to the extension.

WARNING: The File Information dialogue box provides a safe method of opening files that are not used by ModuLab XM. Do not open files from the *project* directory using the standard Windows features, unless you have already seen that files with the same extension appear in the ModuLab XM navigation panel. Otherwise, you could edit a file that is used by ModuLab XM, and the *project* might become corrupt.

5.14.1 Shortcut Folder

In addition to referencing files, the File Information dialogue box can represent a shortcut folder which points to a folder anywhere on the filing system, containing a collection of files. This provides a convenient method of opening files from other applications that might be relevant to ModuLab XM. A Shortcut folder is created as follows:

1. From the File Menu, select Add Shortcut. A shortcut folder will appear at the bottom of the navigation tree. (It doesn't matter which item in the tree has been selected. The shortcut folder always appears at the bottom).
2. Select the Shortcut folder to display the File Information screen as follows:

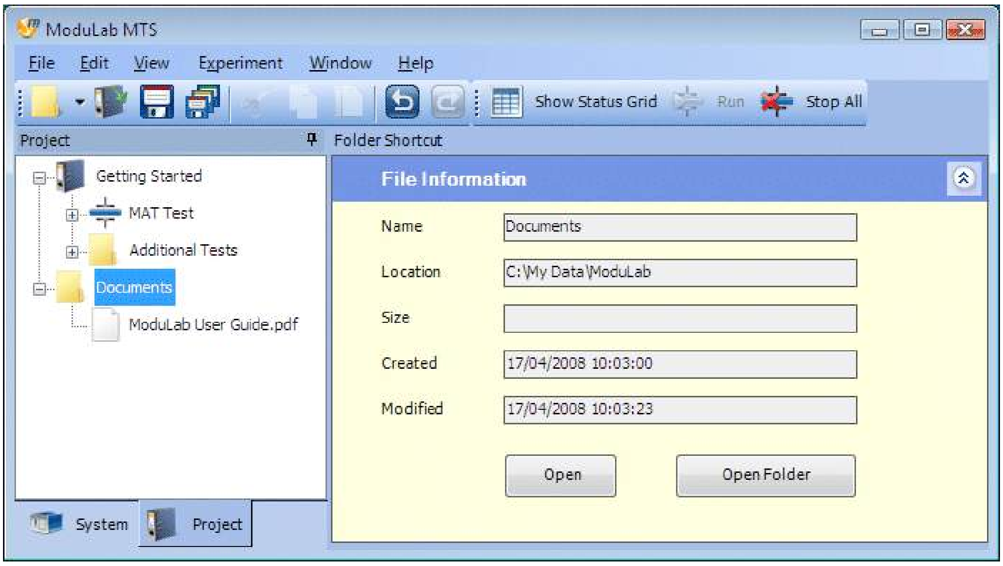


This is the same as the File Information dialogue box described in the previous section, except that it represents a shortcut folder instead of a file, and there is a Browse button so that you can select a destination folder from the filing system. The fields are initially blank because a destination folder has not been specified.

3. Click the Browse button and navigate to a destination folder, then click OK. The shortcut folder in the left-hand navigation panel will be re-named according to the destination folder, and will be populated with all the files and sub-folders. The Browse button will disappear from the File Information

screen and the fields (except the Size) will be filled in with the folder information.

The following screen shows a shortcut representing a folder that contains a copy of this manual.



4. Open the file in the usual way, using the Open or Open Folder buttons.

6. Appendix

6.1 WAVEFORM GENERATION AND MEASUREMENT

The ModuLab XM system applies a waveform to the sample, according to the Step Setup, and then measures the resulting voltage or current using the appropriate connections (2-terminal or 4-terminal).

☞ Step Setup, Section 5.7.

☞ Connections field in the Instrument Experiment Setup, Section 5.3.4.

The materials core module has three amplifiers, and the circuit representing 4-terminal connections is shown in Figure 6-1.

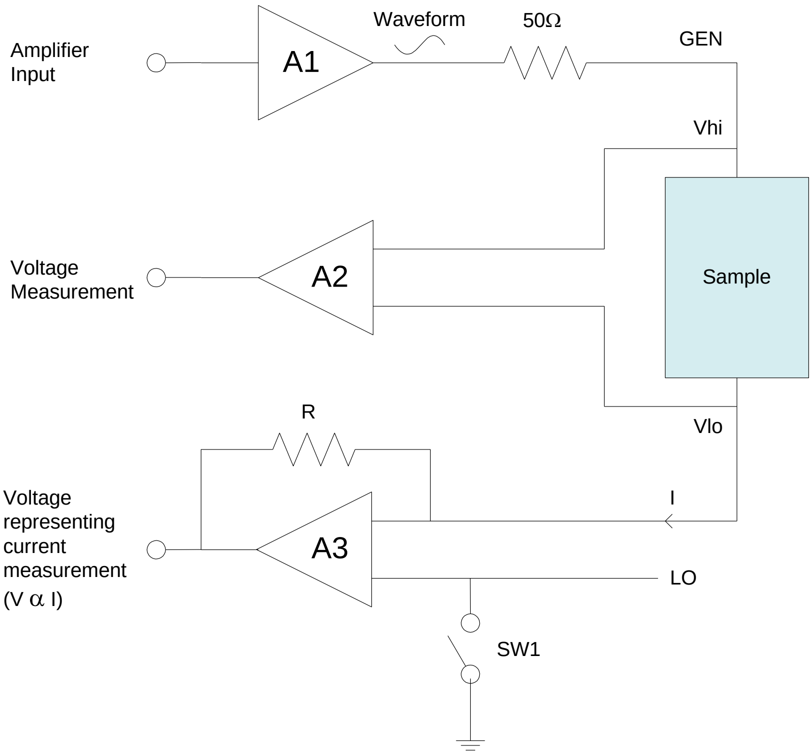


Figure 6-1 Waveform generation and measurement, 4-terminal

An input is applied to the amplifier A1 such that the output is the required waveform. This passes through a 50Ω resistance for cable matching and is applied to the sample as the generated voltage (GEN).

The resulting potential difference across the sample (Vhi, Vlo) is passed through amplifier A2 to the voltage measurement circuit.

The output current (I) is passed through the amplifier A3 which produces a voltage for measurement purposes, proportional to the current.

The corresponding circuit for 2-terminal connections, normally used for high impedance measurements, is shown in Figure 6-2.

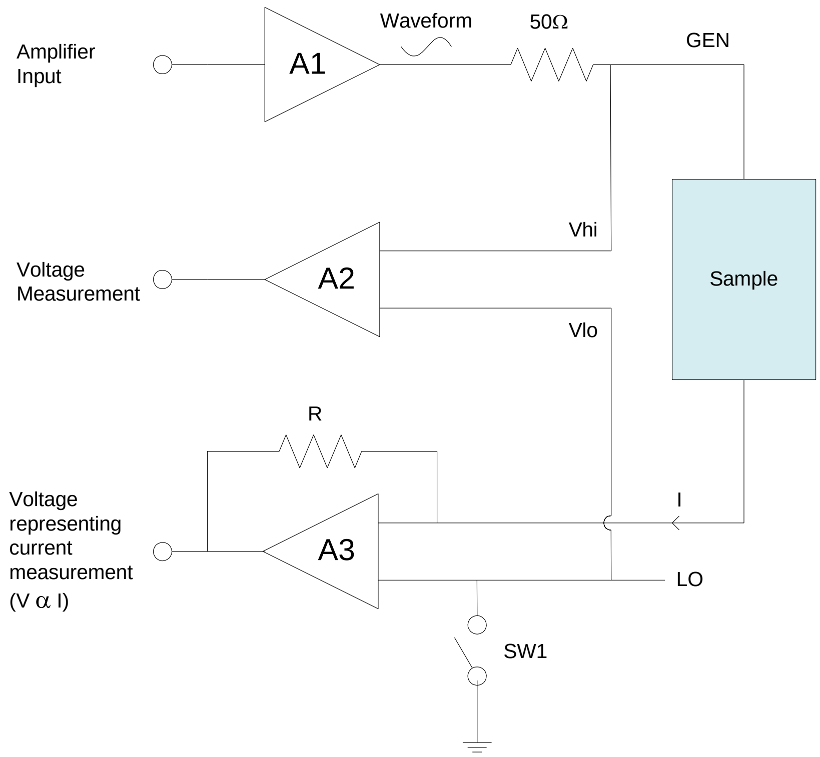


Figure 6-2 Waveform generation and measurement, 2-terminal

In this case, the cable impedance becomes less significant compared with the impedance of the sample, and instead the current losses through the amplifier A2 become more important. To compensate for this, the Vhi and Vlo connections to the sample are not used, and the sockets are internally connected to the output from the 50Ω impedance on A1 and the LO input on A3.

6.2 ENVIRONMENTAL INTERFERENCE AT LOW CURRENT

Low current measurements in the femto-amp range can be affected by electrical interference from the environment, such as electric lighting, office equipment and cables. Mechanical vibrations can also have an effect, if they generate electrical interference within the cables that are used for measurement purposes. These effects are likely to be important in experiments that use the femto ammeter under conditions of low current and high impedance.

☞ High Impedance Materials Testing, Section 3.3.2.3

☞ High Voltage / High Impedance Materials Testing, Section 3.3.2.4

To mitigate these effects, every effort should be made to eliminate electrical and mechanical interference from the environment, by removing equipment that is not needed for the experiment.

The following precautions can also be taken:

☞ A Faraday cage can be used to reduce electrical interference from the environment. (Section 6.2.1)

☞ Tribo-electric precautions can be taken to reduce vibrations that may induce electrical interference within the cables. (Section 6.2.2)

6.2.1 Faraday Cage

To reduce electrical interference from the environment, the sample should be totally enclosed in a Faraday cage, consisting of an electrically conducting metal enclosure which captures the signals from the environment and evenly distributes them in the space around the sample.

The cage must be a continuous metal conducting enclosure with no gaps or empty holes. If the enclosure consists of multiple components (for example a box with a lid), all parts of the box must be electrically connected.

Sockets must be fitted to the cage so that there is good electrical connection between the outer shell of the socket and the metallic body of the cage, and there must not be any insulating washers. The insulating material within the socket, which separates the core from the outer shell, must be PTFE (not PEEK dielectric). BNC connectors will meet these requirements.

The dielectric reference module, supplied with ModuLab XM MTS for testing the system, is designed as a Faraday cage with BNC connectors as shown in Figure 6-3:

Figure 6-3 Dielectric reference module

The ModuLab XM MTS system is supplied with shielded BNC cables so that the shield connects to the body of the cage and the inner core goes through to the appropriate sample electrode.

6.2.2 Tribo-Electric Effects

If there is mechanical vibration in the environment, the inter-connecting cables between the ModuLab XM system and the sample will generate small electric currents, caused by the inner shielding braids and dielectrics rubbing together. These induced currents are normally insignificant, but will cause problems when measuring currents in the pico or femto-amp range.

To mitigate these effects, the sample and all the connecting cables should be secured to a rigid surface, and the Faraday cage, if used, should be internally and externally secure.

6.3 SAMPLE HOLDER

The 12962A sample holder passes a current between two electrodes, across a measured thickness of the sample, for accurate testing of materials at room temperature. It includes a micrometer for measuring sample thickness, which can range from 0.2 to 25.4mm. The impedance measurement range, when using the sample holder with the ModuLab XM system, is <1Ω to >100TΩ.

The sample holder, shown in Figure 6-4, has two parallel electrodes as follows:

- The ‘Hi’ electrode is a standard sized 45mm diameter disc, which can be moved into contact with the sample by adjustment of the micrometer. This electrode is used for measuring all samples, solid or liquid.
- The ‘Lo’ electrode is fixed in position, but can be replaced by a number of alternative versions to suit the diameter of the sample. The standard version, supplied with the sample holder, is for testing solid materials and has a 20mm diameter active area.

☞ Section 6.3.3, Changing The Fixed Electrode Assembly.

The alternative fixed electrodes are available in two accessory kits as follows:

- A solid sample electrode kit, consisting of three fixed electrodes for testing solid materials of different sizes. The active electrode diameters are 10mm, 30mm and 40mm.
- A liquid sample electrode kit, with a single electrode for testing liquid samples.

Figure 6-4 Sample holder with standard 20mm fixed electrode

All fixed electrodes, solid or liquid, utilise guard ring techniques to reduce the fringing effect of stray fields at the edge of the sample. In the case of solid samples, the diameter of the sample should be at least 10% greater than the electrode diameter to avoid fringing.

☞ Section 6.3.2, Electrode Assemblies and Guard Ring.

NOTE: The diameter of the solid sample fixed electrode assembly, including the guard ring, is 45mm, same as the adjustable electrode. The active electrode area is the smaller disc at the centre.

If you wish to improve the accuracy of your measurements, you can use measurement normalisation.

☞ Section 6.3.6, Normalisation

The sub-sections below apply to the 12962A sample holder and the available accessories. For information about other sample holders, including those for high and low temperature applications using cryostats and furnaces, please contact Solartron.

6.3.1 Sample Geometry

The ModuLab XM MTS software requires knowledge of the geometry of the sample, in terms of thickness and electrode area.

☞ Section 5.3.3, Sample setup.

The thickness of the sample can be read from a micrometer digital display that is included as part of the sample holder. The area of the sample is defined by the area of the central Lo electrode. These dimensions are used by the ModuLab XM MTS software to calculate the permittivity of the material (which is independent of the size of the sample), using the formula:

$$\varepsilon = C.d/A$$

where:

ε = permittivity (F/m)

C = capacitance (F)

d = thickness (m)

A = area (m^2)

This allows results from materials of different sizes to be compared.

Results can be displayed using the ModuLab XM software as absolute or relative permittivity. Relative permittivity of the material, also known as the “dielectric constant” is calculated as:

$$\varepsilon_r = \varepsilon / \varepsilon_0$$

where

ε_r = relative permittivity

ε_0 = permittivity of free space (8.85419E-12 F/m)

6.3.2 Electrode Assemblies and Guard Ring

The solid or liquid material sample is measured between the Hi electrode, adjustable from the micrometer, and the fixed Lo electrode assembly which includes a guard ring, separated from the electrode by a layer of insulation. (Figures 6-5 and 6-6).

The purpose of the guard ring is to reduce the effect of stray field lines at the edge of the sample that would otherwise lead to measurement errors. It ensures that the electric field lines are parallel throughout the part of the sample that contributes to the impedance measurement.

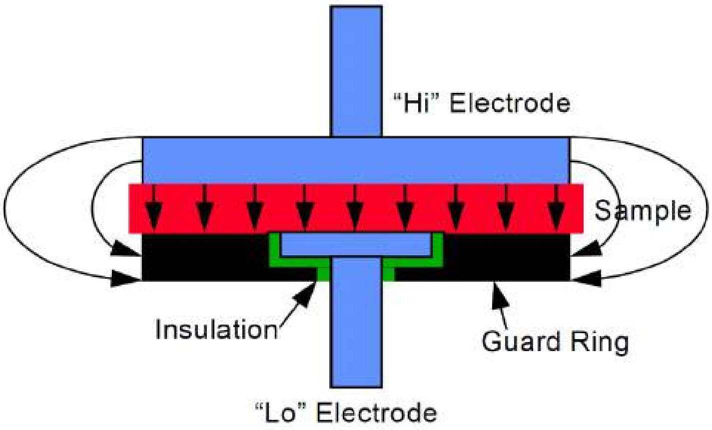


Figure 6-5 Solid sample and electrodes

The guard ring is connected to ground on the sample holder, while the Lo electrode is virtually the same ground potential because the current to voltage converter in the ModuLab XM system (core module and femto ammeter) is a 'virtual earth' device. There is no potential difference between the Lo electrode and the guard ring and therefore the field lines at the edge of the "Lo" electrode are maintained parallel to each other. The impedance of the sample is calculated from the voltage drop across the sample and the current flowing through the central part alone of the sample where the field lines are parallel. The current flowing through the edge of the sample and the air surrounding the sample is not measured – it goes directly to earth and therefore does not contribute to the measurement.

For measuring liquid samples (Figure 6-6), the fixed Lo electrode assembly has a guard ring to maintain parallel electric field lines through the sample, but has the following additional features:

- It is shaped like a dish so that it can hold small samples of liquid.
- It can be disassembled for cleaning.

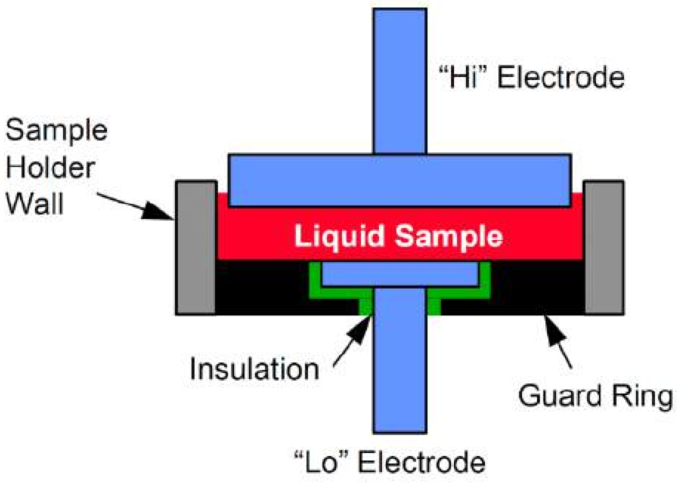


Figure 6-6 Liquid sample and electrodes

The ModuLab XM system should be internally grounded when connected to the solid or liquid sample holders.

6.3.3 Changing The Fixed Electrode Assembly

The fixed Lo electrode assembly can be changed as follows:

1. Using the micrometer, move the travelling electrode as far away as possible from the fixed electrode assembly.
2. Carefully unscrew the fixed electrode assembly from the body of the sample holder, using finger pressure only.
3. Store the electrode assembly in a safe place.
4. Screw the new electrode assembly into the body of the sample holder, taking care to keep the assembly properly aligned with the sample holder to avoid crossing the threads. Tighten the electrode gently against the body, using finger pressure only.

CAUTION: Do not over tighten the fixed electrode.

CAUTION: Do not attempt to separate the components of the fixed electrode assemblies for solid samples (electrode, insulation and guard ring). Any attempt to do so will adversely affect measurement accuracy, and will render the warranty invalid.

6.3.4 Measuring Solid Samples

To measure the electrical properties of solid samples, proceed as follows:

1. Make sure the correct fixed electrode is fitted, according to the sample size.

   ☞ Section 6.3.3.

2. Remove the sample if it is currently held between the electrodes.
3. Turn the micrometer so that the electrodes move into contact with each other.
4. Press the 'Zero/Abs' button, to zero the micrometer display.
5. Toggle the in/mm button to set the display to the required units.

6. Turn the micrometer and place the sample between the electrodes, and adjust it so that the sample is held gently but firmly.
7. Note the reading on the micrometer display.
8. Set up the experiment in ModuLab XM MTS, and enter the sample thickness and electrode area in the Sample Setup. (The area is based on the diameter of the fixed Lo electrode, without the insulation and guard rail).

   ☞ Section 5.3.3, Sample Setup.

9. Run the experiment and take measurements using the ModuLab XM MTS software.

6.3.5 Measuring Liquid Samples

To measure the electrical properties of liquid samples, with the liquid sample electrode fitted, proceed as follows:

Figure 6-7 Liquid sample holder

1. Make sure all liquid is removed from the liquid sample electrode.
2. Zero the micrometer, same as for the solid sample electrode.

   ☞ Section 6.3.4, steps 3 to 5.

3. Turn the micrometer and adjust the position of the upper electrode so that it is slightly greater than the required sample thickness.
4. Place the sample liquid into the lower dish electrode so that it almost reaches the upper electrode.
5. Move the upper electrode carefully towards the lower electrode until the required sample thickness is displayed. The upper electrode is slightly smaller than the dish of the lower electrode assembly so that excess liquid can escape around the side of the upper electrode. Make sure a small amount of liquid rises up, as this will ensure that the upper electrode is fully in contact with the liquid and there are no air spaces. However, do not go past the required thickness, otherwise too much liquid will rise up, and it will distort the results because it is not in contact with the front face of the upper electrode.
6. Set up the experiment in ModuLab XM MTS and enter the sample thickness and electrode area in the Sample Setup. (The area is based on the diameter of the fixed Lo electrode, without the insulation and guard rail).

   ☞ Section 5.3.3, Sample setup.

7. Run the experiment and take measurements using the ModuLab XM MTS software.

6.3.6 Normalisation

For optimum accuracy when using liquid or solid sample holders, you should make use of the normalisation technique. This will reduce the errors due to fringing, connections, etc.

There are two possible methods of normalisation: matched cell geometry and matched cell capacitance. Both have advantages. Matched cell capacitance gives the best cancellation of instrumentation errors, whereas matched cell geometry optimises the cancellation of fringing effects. Select the one that gives you the best results.

6.3.6.1 Method 1 - Matched Cell Geometry

1. Take measurements on the sample in the usual way, making a note of the micrometer setting.

   ☞ Sections 6.3.4 and 6.3.5.

2. Remove the sample, clean the electrodes if necessary, and reset the micrometer to the setting noted above. This will create an air gap cell with the same dimensions as the cell used for the sample.
3. Measure the impedance of this air gap cell at the same frequencies as before, and use this data as the normalisation data.

6.3.6.2 Method 2 - Matched Cell Capacitance

1. Take measurements on the sample in the usual way and note the capacitance of the sample.

   ☞ Sections 6.3.4 and 6.3.5.

2. Remove the sample and clean the electrodes if necessary. Calculate the air gap, d (in m.), required to create an air gap cell with the same capacitance as the sample, using the equation:

   $$d = A\varepsilon_0/C$$

   where:

   A is the area of the cell (m^2)

   C is the required capacitance (F)

   ε_0 is the permittivity of free space (8.85419E-12 F/m)

3. Set the micrometer to the calculated air gap, measure the impedance of this air gap cell at the same frequencies as those used for the sample measurements, and use this data for normalisation.

6.4 CRYOSTAT

The 129610A Cryostat system is available for testing materials in the following temperature ranges:

- From 78K to 600K using liquid nitrogen.
- From 5K to 600K using liquid helium.

This model of the cryostat system (shown in Figure 6-8) is a special design, produced by Janis Research Company in collaboration with Solartron, to meet specific requirements of temperature range control, and to place the sample in a static thermal exchange gas (for example dry helium), to provide repeatable tests on materials that could otherwise be affected by contact with cryogen vapor in flowing vapor type systems.

The cryostat may be used for the following typical applications:

- Development of advanced polymer materials;
- Pharmaceutical applications including drug delivery and freeze drying;
- Semiconductor materials;
- Composite materials and coatings;
- Display materials;
- Aerospace materials.

Figure 6-8 Cryostat

The internal assembly of the cryostat system is shown in Figure 6-9.

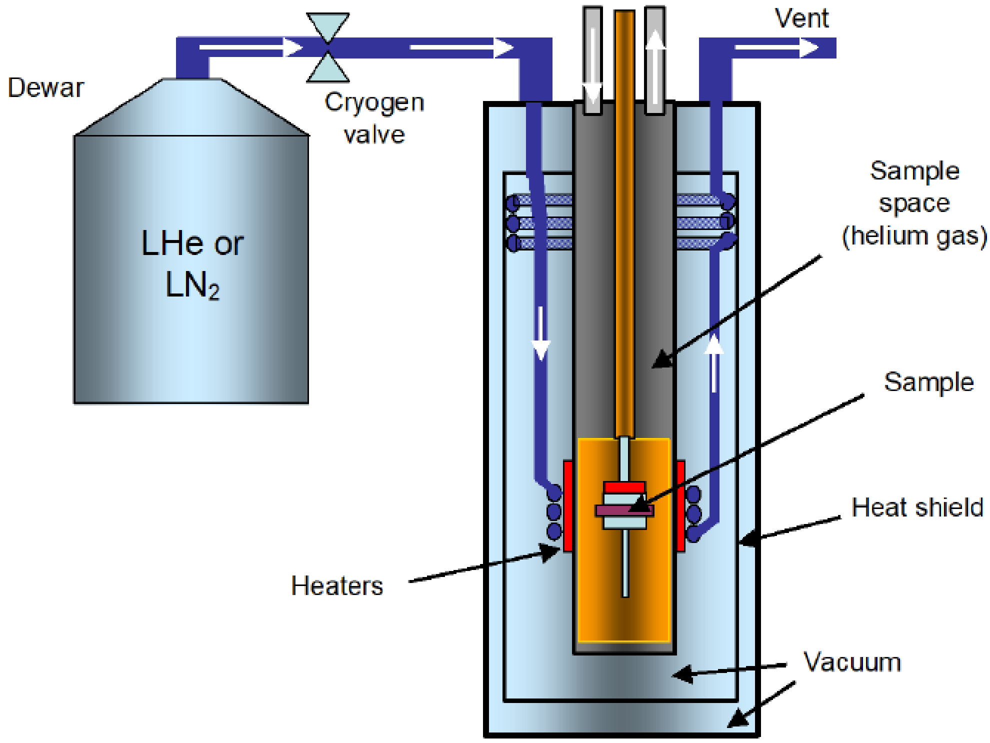


Figure 6-9 Cryostat internal assembly

The sample is located in a sample space containing an inert atmosphere of helium gas. Outside the sample space there are two vacuum chambers separated by a heat shield, to provide insulation from the external environment. Temperature control is achieved by a cooling capillary and two heating coils, located in the inner vacuum chamber around the sample space. The flow of cryogen through the capillary and the power to the heaters are adjusted so that they work against each other to achieve the required control, while minimising the loss of cryogen. The heaters are turned off to achieve the lowest temperature, and the cryogen is turned off when temperatures above ambient are required.

The cryostat has the following features:

- Solid and liquid sample holders are included for testing a wide range of materials including solids, gels, oils, powders, pastes, etc.
- The sample holders use guard ring techniques to reject "fringing" effects at the edge of the sample.
- High and low impedance material samples can be accurately tested using two or four terminal sample connections.

  ☞ The connection type is identified in the ModuLab XM MTS software, in the Instrument Experiment Setup, Section 5.3.4.

- Fast and accurate temperature settling using a dual channel temperature controller. There are two heaters, one to achieve the required temperature quickly, and the other to maintain accurate temperature control.

- The system operates with continuous flow of cryogen via a transfer line from the dewar.
- The cryogen may be either liquid nitrogen or liquid helium, which must be selected at the beginning of the experiment, and there is no mixing of cryogens.
- The inert atmosphere of helium gas in the sample space prevents cracking and swelling that might otherwise occur if the sample was placed directly in the flow of cryogen.

7. ModuLab XM MTS Support

7.1 RANGE OF SUPPORT PROVIDED

Solartron Analytical provides you with full support to enable you to use the ModuLab XM system to your best advantage. The support includes:

- A full set of user guides, available in printed form, on CD, and on-line from the Solartron Analytical website.
- On-line Help from the ModuLab XM user interface, comprising:
  - The ModuLab XM Help Text. From the Help menu, select Contents or Index.
  - Answers to a list of Frequently Asked Questions, covering all aspects of ModuLab XM use. From the Help menu, select FAQ.
  - An on-line version of the User Guide for the ModuLab XM User Interface. Right-click on the *project*, in the left-hand navigation panel, and select Explorer, then open the Documents folder, under the ModuLab XM folder.
  - A check for new versions of the ModuLab XM software. From the Help menu, select Check for updates.
  - Technical support, including locations of support centres for worldwide servicing of equipment. From the Help menu, select Technical Support.
- Access to the Solartron Analytical website, which contains a wealth of information and guidance on the use of Solartron Analytical precision instrumentation for your particular application.

  ☞ Solartron Analytical Website, Section 7.2.

7.2 VISITING THE SOLATRON ANALYTICAL WEBSITE

To visit the Solartron Analytical website, click on in the appropriate button in the ModuLab XM toolbar, or alternatively enter the following address in your browser:

www.solartronanalytical.com

This site contains full information on the products available from Solartron Analytical for applications in the fields of electrochemistry, energy storage, corrosion, materials, control, electronics test, and metals analysis. Click on the various boxes in the site to find out which of our precision instruments may best suit your particular application. Solartron Analytical can provide a full range of technical expertise, in the form of technical notes and technical training to guide you in this. You can also contact our sales and marketing team through the website to get immediate expert advice.

When you need an upgrade for your ModuLab XM software you can download this from our website. This enables you to keep your ModuLab XM system up to date, and in line with the very latest improvements.

8. Glossary of Terms

This chapter contains a glossary of terms, including abbreviations, that are commonly used in the manuals associated with the ModuLab XM system.

Term	Meaning
Analyzer	The function that measures the frequency response of the *test unit*. The analysis techniques used are single sine and *Fast Fourier Transform*.
Auxiliary	Used in the context of the measurement of elements within a *test unit*, i.e. through an auxiliary *channel*.
Booster	An internal module that can be used to stimulate the sample and take measurements at high power ratings.
Channel	The combination of *input* and *output* connections required to measure a single *test unit*.
Chassis	A mechanical structure, containing *slots*, that is used to house *modules*. The chassis also embodies a power supply and an Ethernet hub.
Core Product	A *module*, within the *system*, that is able to make standalone measurements.
Decision	An item within the *experiment* structure that contains *options* to be evaluated so that *steps* can be carried out.
Experiment	An action to be performed on a sample, including a series of *steps*, using a specific hardware configuration. During each *step* a stimulation signal is applied to the sample and measurements are taken. Results are accumulated and may be presented as graphs and *reports*. In terms of the Windows filing system, an *experiment* is a *folder* which is recognised by ModuLab XM because of its contents.
Experiment Type	A category of *experiments* in which a number of hardware configurations are available for a range of similar applications. Experiment types include General Materials Testing, High Voltage Materials Testing, etc.
Femto Ammeter	An optional *module* that can be included in an *instrument group*, to provide low current measurements of high impedance samples.
Folder	A location in the Windows filing system containing data that is meaningful to ModuLab XM. A *folder* can be recognised by ModuLab XM as a *project*, *experiment* or *report folder*, depending on its contents. A *folder* may also be added, within a *project* structure, as a location for any data that is useful to the *project*, including sub-*folders* that represent *experiments* and *report folders*.
FFT	Fast Fourier Transform.
High Voltage Module	An optional *module* that can be included in an *instrument group*, together with a materials core module, to provide high voltage stimulus to a sample and take measurements.

Impedance	The relationship between voltage and current in AC systems (the AC equivalent of DC resistance).
Instrument Group	A combination of *modules* that work together to stimulate a sample and take measurements. The group contains a materials core module and a number of optional *modules* as required.
Loop	A control feature within an *experiment* that enables other controls to accumulate data on a repetitive, cyclic basis.
Loop Type	A number of different types of *loop* are available. There is the standard *loop*, for repeating any specified sequence of steps, and there are loops which can be configured for repeating impedance steps with different AC amplitudes or DC bias levels.
Module	Any single product that can be fitted individually into a *chassis slot*.
Noise	Random fluctuations in sample voltage.
Option	A condition to be evaluated under a *decision*, to enable *steps* to be carried out
Project	A top-level *folder* in the Windows filing system which may contain *experiments* and other related items. ModuLab XM recognises the *folder* as a *project* because of its contents.
Report	A document describing an *experiment*, which can be opened in a word processor for editing and printing. The document may contain *experiment* settings and results, including connection diagrams, graphs, tables and user comments. The data displayed in a *report* is based on the graph files associated with the *experiments*. Any number of document files, each with the RTF extension, can be generated by the Report Writer under a *report folder*, and can then be displayed and edited using any Windows application that supports the RTF format.
Report Folder	A *folder* which is recognised by ModuLab XM as a container for *reports*. The Report Writer appears when the user clicks on the *report folder* in the navigation panel, and *reports* can be generated from any number of graph files.
Slot	A space in a chassis into which a single width module can be inserted.
Step	A definition of how an *experiment* will progress over a specific period of time, including the stimulation signal and the measurements to be taken. Any number of sequential *steps* can be included in an *experiment*.
Step Type	The general shape of the stimulation signal to be applied to the sample during a *step*, for example Linear Sweep, Triangular Sweep, etc. The complete definition of a *step* requires values to be applied to the *step type*, such as the signal level, duration, and upper and lower limits.

System	A combination of one or more *modules*, in one or more *chasses*, and other equipment (temperature controllers, cryostats, ovens, etc.) all operating under software control from a PC.
Temperature Control	A control feature within an *experiment* that applies temperature variations to a sample.
Test Unit	Any item under test being measured by the *system*.

9. Index

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Solartron pursues a policy of continuous development and product improvement.
The specifications in this document may therefore be changed without notice.

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