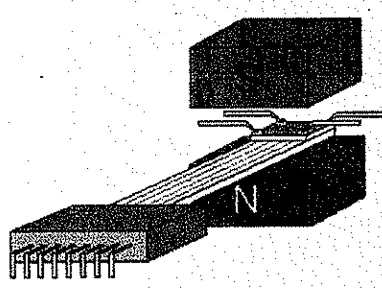
TATE LAB

Hall and Van der Pauw Measurement System

Software Package

Version 2.0



USER'S MANUAL

MMR Technologies, Inc.
1400 North Shoreline Blvd., Suite A5
Mountain View, CA 94043-1346

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TABLE OF CONTENTS

Section 1. Introduction

This manual presumes that the reader is familiar with four-probe Van der Pauw and Hall effect measurement methods.

The software package ("program") presented here supports the Hall and Van der Pauw Measurement System of MMR Technologies. This System includes a K-20 Programmable Temperature controller, H-50 Hall and Van der Pauw controller, MPS-50 Programmable power Supply, M-50 Benchtop Electromagnet, MMR Thermal Stage with Cryogenic Refrigerator, Dewar and vacuum accessories. System control is provided by an IBM compatible computer. The K-20 Temperature Controller adjusts and maintains the temperature of the MMR Thermal Stage over a wide temperature range, with high accuracy and stability. The H-50 Hall and Van der Pauw controller provides four probe method measurements of the electrical parameters of the samples. The M-50 Benchtop Electromagnet provides the magnetic field over the studied sample and the MPS-50 Programmable Power Supply controls the magnitude of that magnetic field. These scientific instruments were designed as separate computer controlled devices. The program provides the user with a friendly interfacing environment for these instruments, and automates the data acquisition process.

Section 2. Definitions

The following are the definitions of the terms which will be used in this manual. The words used in the definitions (written in italic) are also defined in this section.

1. **Data point.** The system condition defined by the set of the experiment parameters which exist when the system is acquiring data. The experiment parameters include *fixed parameters* and *experiment variables*. The experiment may contain one or several *data points*. If the experiment contains only one *data point* (Single point mode), then no *experiment variable* is present and experiment conditions are fully defined by the *fixed parameters*. If the *experiment* contains more then one *data point* (Curve mode) then each *data point* corresponds to a certain value of the *experiment variable*.

2. **Experiment**. The process that includes: setup of the experiment *fixed parameters*; initiating a sequence of settings of the *experiment variable*, starting from *Start Value* of *Experiment Variable* and finishing at the *Finish Value* of *Experiment Variable*; data acquisition at each *data point*; and calculation of results and presentation.

3. **Data Set.** The set of measurements acquired by the measurement process for one data point. Example: For the Van der Pauw measurements each data point has one data set, acquired by the

process "Four probe Resistivity measurement". For the Hall measurement we have to take two data sets for each data point: first, we have to get data by the process "Four probe Resistivity measurement", and then we have to acquire data by the process "Four probe Hall Effect measurement". The Resistivity calculated as a result of the first data set is to be used to calculate the results of the second data set.

4. **Experiment Variable**. The experimental environment setting which takes a different value for every data point. Only one experiment variable may exist for each experiment. There are three possible experiment variables in the Hall and Van der Pauw Measurement system: Current, Temperature and Field. The *Experiment Variable* has the following settings: *Start Value*, *Finish value*, *Step Value* and the mode by which the variable changes its value. In addition, the Temperature variable also has a *Standby Temperature* value. For details see Section 8, "Experiment Setup".

5. **Fixed Parameters**. The experimental environment settings which keep their values fixed during the experiment run.

6. **Start Value** of *experiment variable*. The *experiment variable* value which corresponds to the first *data point* of the *experiment* .

7. **Finish value** of *experiment variable*. The *experiment variable* value which corresponds to the last *data point* of the *experiment*.

8. **Step value** of *experiment variable*. The difference between two consecutive settings of the *experiment variable*. The Step value makes sense only if the *experiment variable* changes its value in the linear mode.

9. **Standby Temperature.** Temperature to which the Thermal stage is to be directed after the *experiment* has been completed.

10. **Target** value**.** The value of the experiment parameter or variable which is to be set by the system.

11. **Read** value**.** The actual acquired value of the experiment parameter or variable.

12. **Temperature Ramp.** The speed with which the temperature can be adjusted to the *target value*.

13. **Data is present in the system.** This system condition means that the system contains experimental data acquired either by running the experiment or by loading data using an execution of the "Load File" procedure.

Section 3. System Requirements

The program will work on any PC AT compatible (386 or better) computer running Windows 3.1. The computer should have at least 1 Meg of RAM memory. A color monitor, mouse, and math co-processor are recommended.

The program supports communication of the computer with the controllers via serial ports COM1 - COM4 or the IEEE 488 interface. In the case of use of the serial ports, the system requires three COM ports to be available. If this requirement happens to be inconvenient, then the program can also work with only one COM port using the MMR Splitter Box model C1820. If one wishes to use the IEEE 488 interface, MMR can supply the special interface board (Capital Equipment Corp.) and cables. Contact MMR sales for further information.

Section 4. Hardware Setup

4.1. Three COM Port Configuration

As mentioned above, you have three options regarding how to connect the controllers to the computer. The first option is shown in Fig. 1.

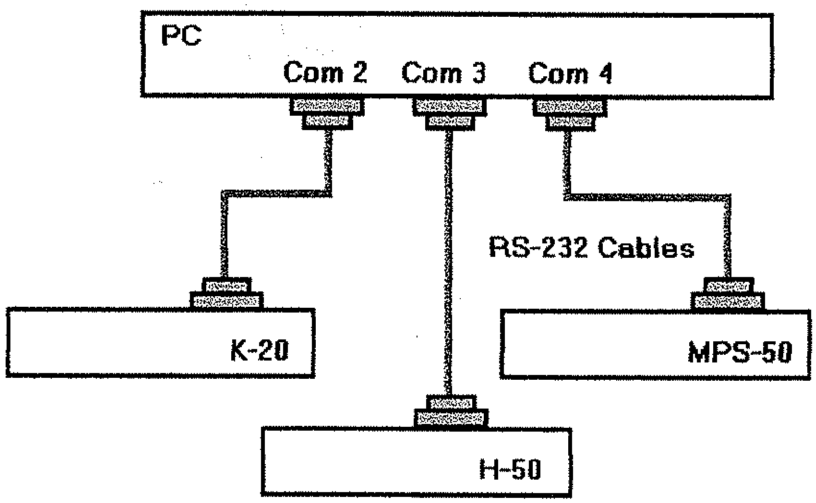


Fig. 1. Three COM port configuration

This scheme requires that three serial ports in your computer are available for the system communication. One more serial port is needed to control the mouse, so the system requires four serial ports in total. The standard PC configuration usually supports only two serial ports, so in this configuration additional serial ports have to be specified when ordering the computer system. If the system has been purchased without a computer, then the user can install an additional card with two serial ports in the computer to be used with the system.

If you use this scheme, then connect the controllers to the computer as shown in Fig. 1 using standard serial cables. The given configuration is not mandatory, you can connect any controller to any serial port, just memorize any different interconnections. You will have to make the corresponding changes in communication setup. (See Section 7.4, "Communication Setup".) All controllers must be set to the factory default communication speed of 4800 Baud. Refer to each controllers' manual to check these settings.

4.2. Splitter Box Configuration

The second way to connect controllers to the computer is shown in Fig. 2.

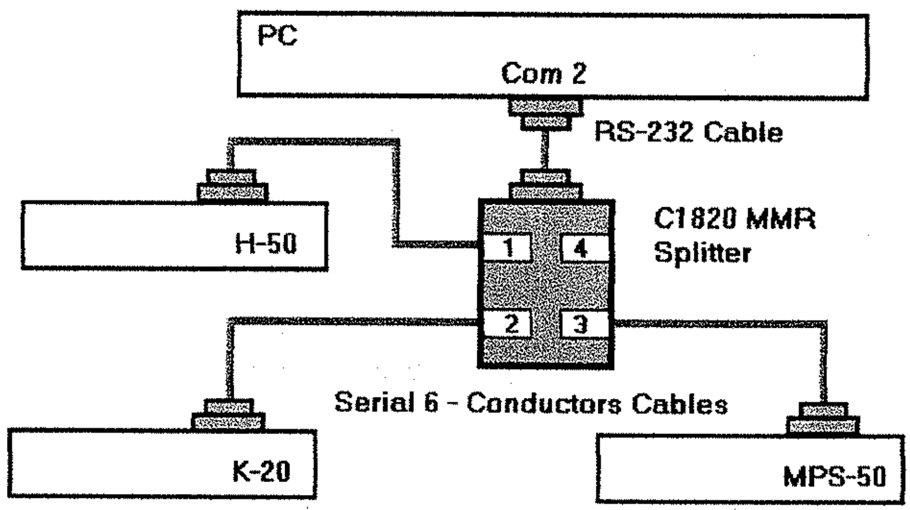


Fig. 2. Splitter Box Connections.

If for any reason you do not have three available serial ports in you computer, you can establish system communication using only one serial port. To do so you need to use the MMR Splitter box Model C1820.

Connect the RS-232 Input of the Splitter box to any available serial port using a standard serial communication cable. Then connect the controllers to the Splitter box as shown in Fig. 2. This configuration is mandatory, so you have to connect the H-50 to Port 1 of the Splitter box, the K-20 to Port 2 and MPS-50 to Port 3. To make these connections you have to use special 6-pin communication cables provided by MMR with the Splitter box. The Splitter box must be set to Mode 3. All controllers must be set to the factory default communication speed 4800 Baud. Refer to the Splitter box's and controllers' manuals to check these settings. See Section 7.4 for additional communication setup information.

4.3. IEEE-488 Configuration

The third communication option is the GPIB (IEEE-488) Interface. To use GPIB your computer must be equipped with an IEEE-488 Interface Card. The MMR Software and Hardware supports the Capital Equipment GPIB card, which can be supplied by MMR or purchased directly from Capital Equipment Corporation. Contact MMR for board specifications.

The IEEE-488 interface connections are shown in Fig. 3.

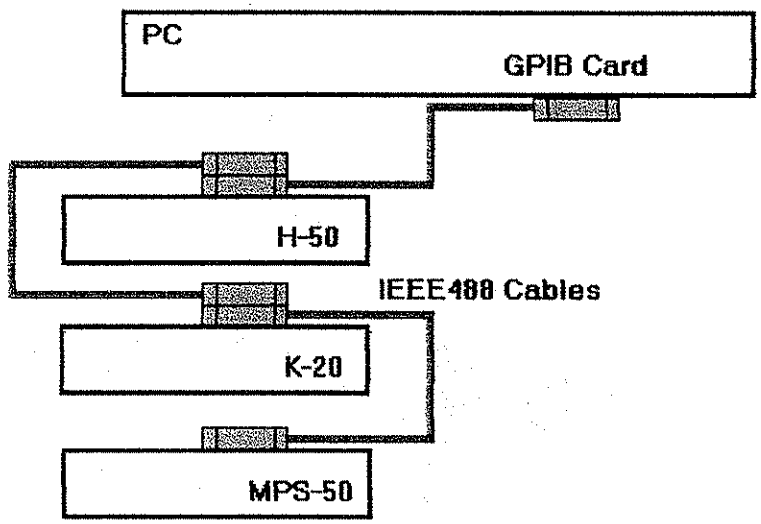


Fig. 3. IEEE-488 configuration.

You can connect the controllers and computer using either daisy-chain or star configurations. You can set IEEE-488 addresses of the controllers in the range from 1 to 30. Refer to the controllers' manuals for how to set the address. No two controllers may have the same address, and none of them may have address 21, which is reserved for the computer IEEE-488 unit. See Section 7.4 for additional communication setup information.

4.4. Magnetic Field

If your system does not use the magnetic field for measurements, then go to section 4.5. The magnetic field can be produced by the M-50 Electromagnet. The M-50 can be powered either by the MPS-50 Programmable Power Supply, or by any other power supply with a similar output.

If you use the MPS-50 then connect your electromagnet power leads to the F+ and F- terminals on the back panel of the MPS-50. (For details refer to MPS-50 Manual). With the MPS-50, the system can make Hall measurements in automatic or semi-automatic regimes as well. The **automatic regime** means that system produces and controls the magnetic field according to experiment settings, so the process of taking data can be unattended. The alternative **semi-automatic regime** means that every time the system needs to set the field to a certain value, the system operator gets a corresponding message. The required field value is then set by the operator and system operation continues.

If you use a third party power supply to produce the field then connect your electromagnet power leads to the output terminals of the power supply. If this power supply can be controlled by an external voltage, you can configure the MMR system to make Hall measurements either in automatic or semi-automatic regimes. To control the Power supply in the automatic regime the system produces a control voltage on the H-50's Probe 5 output. If you want to use this control mode then connect the H-50 Probe 5 connector to the control input of your power supply. You can find more details on this in Section 8, "Experiment Setup".

If the Power supply can not be controlled by an external voltage, then the system can make Hall measurements in the semi-automatic regime only.

4.5. Dewar

Connect the MMR Hall Dewar containing the installed sample to the H-50 using four TRIAX cables. We do not describe the process of the sample mounting. This process is explained in details in the H-50 Manual. We presume that the MMR Hall Dewar contains an MMR Thermal Stage and a Hall sensor to measure the applied magnetic field.

Connect the "Refrigerator Port" on the H-50 back panel to the ribbon cable connector on Hall Dewar using the four foot long 20-lead ribbon cable.

Connect the "K-20 Port" on the H-50 back panel to the "Refrigerator Port" on the K-20 back panel using the short 20-lead ribbon cable.

Install all hardware components needed to produce vacuum and cooling. Refer to the MMR Low Temperature Hall System Dewar Manual.

Your System is now ready to acquire experimental data.

Section 5. Program Setup

5.1. Turn on your computer and start Windows 3.1.
5.2. Insert the setup disk into drive B:.
5.3. In the File Manager select Run from the file menu.
5.4. Type "B:\Setup" and press Enter.
5.5. Follow the directions of the setup program.
5.6. The setup program will install all files on the hard drive and create a program group "MMR Hall and Van der Pauw Measurement System".

Section 6. Getting Started

6.1. Turn all controllers on.
6.2. To start the program open the "MMR Hall System" window and double click the mouse on the Hall and Van der Pauw System icon. One can also start the program using the other conventional windows techniques from the Program or File Manager by executing Hall.exe.
6.3. The System introduction window will come up, as shown in Fig. 4.

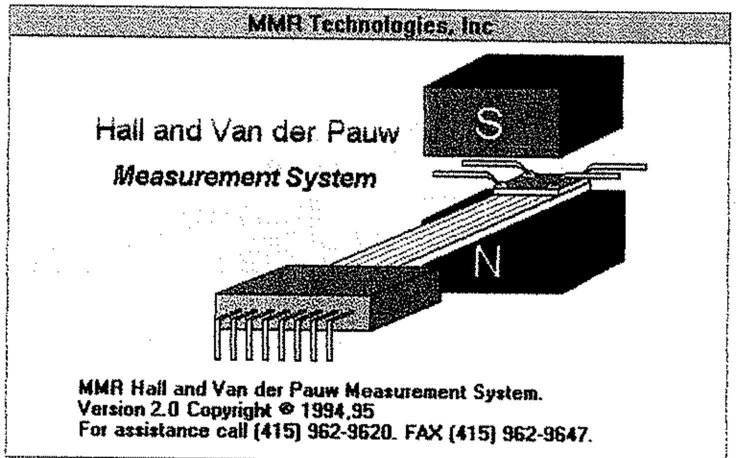


Fig. 4. Program introduction window.

After a few seconds this window will automatically be replaced by the MMR Hall and Van der Pauw System Main Window as shown in Fig. 5. When you start the system for the first time, you will get a message "System did not identify correct Hall.cfg. Will use default values." Do not be concerned about this. The configuration file, Hall.cfg, is created automatically when you quit the system and saves all system settings. So, when you start the System again, this message will not come up, unless you remove the Hall.cfg or re-install the system to another directory.

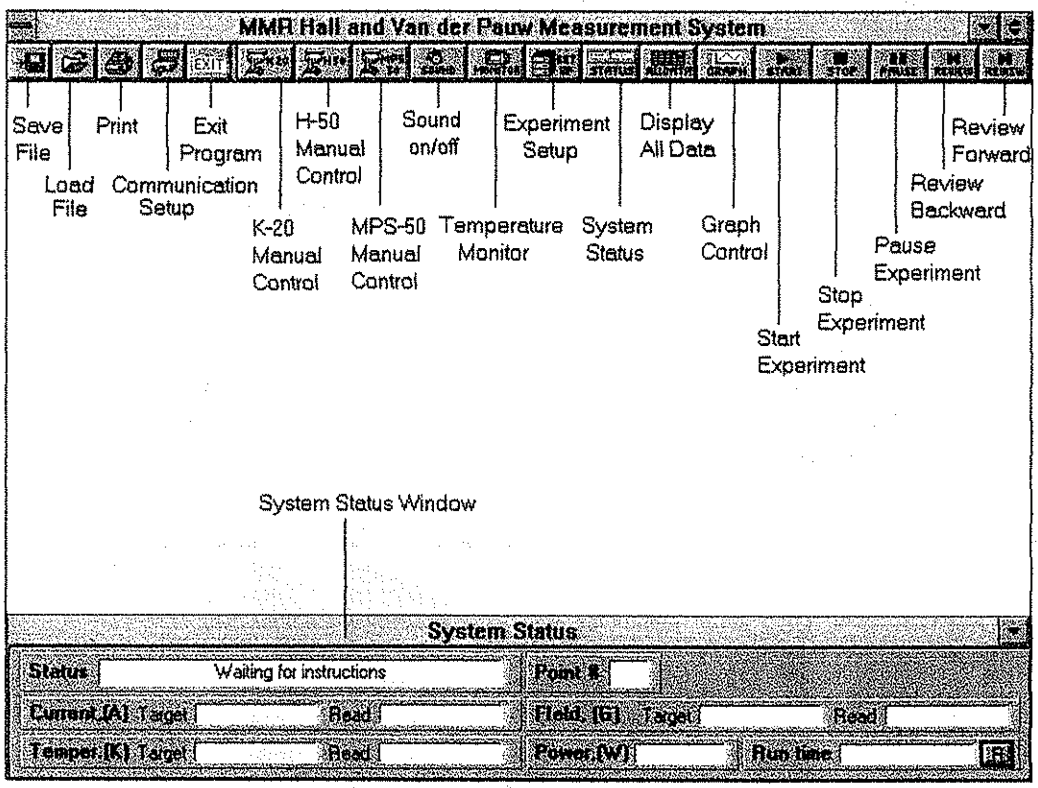


Fig. 5. Main window and System Status window.

6.4. The next step is the setup of communication parameters in the running program. The setup process is described in details in Section 7.4, "Communication Setup". You do not have to repeat setup when you start the program next time because the program automatically saves these settings on exit to the Hall.cfg file and restores them when you start the program.

6.5. To test communication with the system controllers use the Manual Control windows as described in Section 7.6, "K20 Manual Control, H-50 Manual Control, MPS-50 Manual Control". Send any commands to the controllers. You can use, for example, the TS (Type of Sensor) command to test the K-20, DE (Defaults) to test the H-50, and RV (Read Voltage) to test the MPS-50. Then the K-20 has to respond with the message describing the temperature sensor, the H-50 has to respond "OK", and the MPS-50 has to respond "0.00 V". These messages mean that communication to each controller is OK.

6.6. If any errors have occurred then corresponding messages will be displayed. First make sure that your cable connections correspond to the settings in the Communication Setup window (See Section 7.4, "Communication Setup"). The message "Communication Error" means a hardware or configuration problem exists. Check if power to the controller is on; check if communication cables are connected properly; check, if the communication cables are connected to the correct COM ports; check if the Baud rate setting of the controllers is 4800 (refer to the Controllers' Manuals). If you use the IEEE-488, check the address settings. If you use the Splitter box, check if controllers are connected to the box exactly as shown in Fig. 2 and if Splitter Box was set to mode 3. If you get an error message that a certain COM port is unavailable, this indicates that there is hardware conflict in your computer, i.e. another system device has been configured to use this COM port. This could be a mouse, a modem, etc. To resolve this conflict, use a different COM port. Usually, this message will be accompanied with the corresponding Windows error message. Do not be alarmed, this kind of error does not cause any damage to other applications that are currently running.

6.7. The next step is the Experiment Setup. This process is explained in Section 8, "Experiment Setup."

Section 7. Program Functions and Controls

The MMR Hall and Van der Pauw System Main Window is shown in Fig. 5. At the top of the screen one can see a tool bar that provides control of all system functions. All command buttons on this tool bar will be explained in detail in this Section.

7.1. Save File Button

This command button is used to save on disk the data that has been acquired. When you click the button, the Save Experimental Data window will appear as shown in Fig. 6. To execute the Save File operation, data must be present in the system. If no data is present, then a message alerting the user to this fact will be displayed.

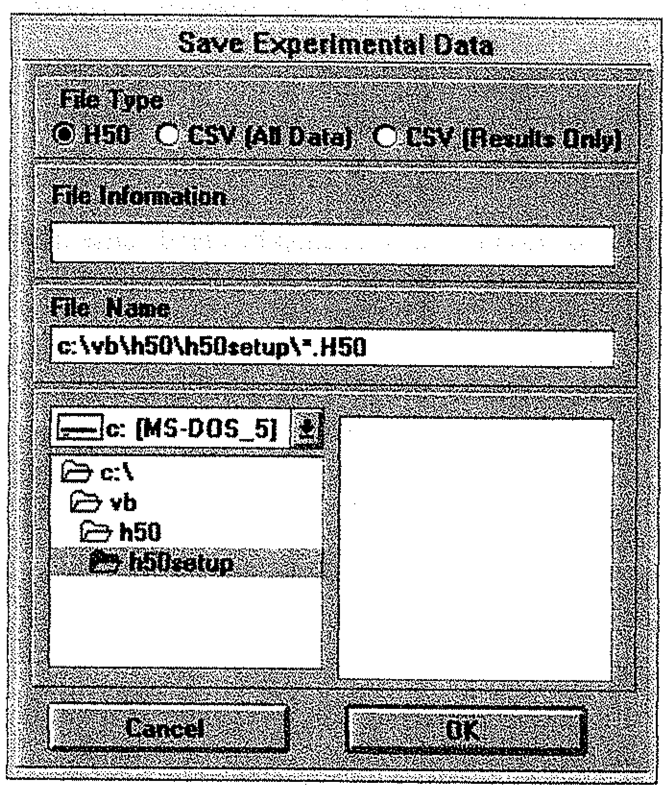


Fig. 6. Save File window.

Select the file format by clicking the desired option button in the format selection box.

The first option is "H50" format, this saves the file in a special format that is readable by the MMR Hall and Van der Pauw program. This makes it possible to load and study this file later using this software. When you save the file in "H50" format, you can also input a data file information string. This information will be retrieved, when you re-load the file. To enter the file information you should click the mouse on the File information text box, and then type the string (up to 40 characters) using the keyboard. All system parameters are saved automatically when you select this file format.

The two other options use the CSV - Comma Separated Values format. The difference between the two is that the "All data" option saves all acquired information including intermediate readings which have been used to calculate results. The "Results Only" option skips all intermediate data and saves only the results. This format is compatible with the popular spread sheets software packages, such as Excel. Because data is saved in ASCII code, it is readable by any text editor. If you save a file in this format, you can use the powerful data presentation tools of the spread sheets, but you would not be able to study this file later using the Hall program. If you do select one of these options, you can also input the data file information string, which will be saved in the file and presented in the first cell of the data sheet.

To enter the file information you should click the mouse on the File information text box, and then type the string using the keyboard.

Notice: You can save the same file in both formats. The "H50" data file can be loaded by the program and then saved in a CSV format.

Enter the name of file to be saved. Click the mouse on the file name text box and then enter the full file name using the keyboard. If you want to change the active drive or directory, you have to double click the mouse on the needed item in the directory/ drive lists.

Click OK button. You will get the message "File is saved". Click OK again.

7.2. Load File Button

You will use this command button if you want to study the content of a previously saved H50 data file. If you click the mouse on this button then the "Load H-50 Data File" window will appear as shown in Fig. 7 (See the following page).

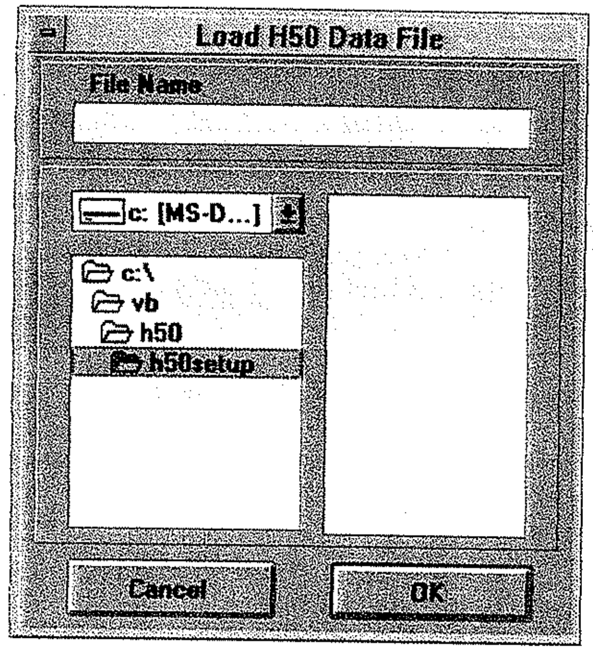


Fig. 7. Load File Window.

Select the file to be loaded. If you want to change the active drive or directory, you have to double click the mouse on the needed item. File selection can be made by clicking on the file name. You can also click the mouse on the file name text box and then enter the full file name using the keyboard.

Notice: You can only view files saved in the special H50 format. (See Section 7.1, "Save File".)

Click OK button. The selected H50 data file will be loaded. Double clicking on the file name in the file directory causes the same action.

You can study the data using " Acquired Data" window or build graphs. (See Section 7.11, "Display All Data" and Section 10, "Graphs"). The Data File Information which has been saved (as explained in the previous Section) can be read in the "Acquired Data" window.

7.3. Print Button

This command button is used to produce hard copy of the collected data. When you click the mouse on this button, the "Printing Control" window will appear as shown in Fig. 8 (See the following page). To generate a printout, experimental data has to be present in the system. If no data is present in the system, then a message alerting the user to that fact will be displayed.

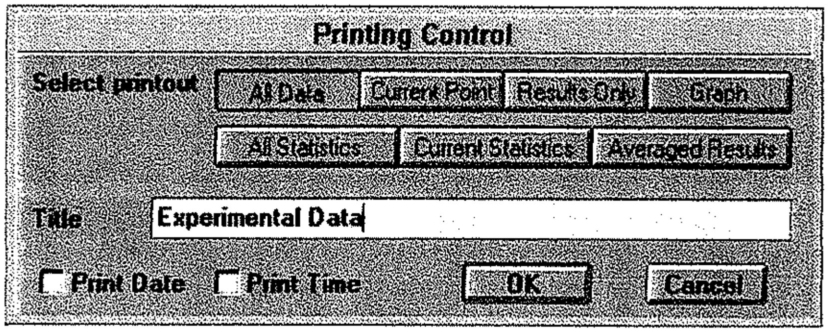


Fig. 8. Printing Control Window

There are seven printout options: **"All Data"**, **"Current Point"**, **"Results Only"**, **"Graph"**, **"All Statistics"**, **"Current Statistics"**, **"Averaged Results"**.

The **"All Data"** option will produce a printout of all collected data points, all intermediate data readings, and all calculated results.

The **"Current Point"** option will produce a printout of all intermediate data readings, and all calculated results for the data point number currently displayed in the "Acquired Data" window.

The **"Results Only"** option will produce a table of the experimental results, waiving all intermediate readings.

The **"Graph"** option will produce a printout of the graph of collected data. Prior to selecting this option you have to build the graph using the graph output tools (See Section 10, "Graphs"). Otherwise the push-button "Graph" will be disabled. The image of the graph which is present in the "Data Curve" window will be copied to the printer.

The following three options are not available for the Linearity check. They will be also disabled for the loaded data files that have been created by the earlier versions of the program and do not contain statistics data. A corresponding message will come up during the loading of the data file of old type.

The **"All Statistics"** option will produce a printout of the statistical calculations for all experiment variable values in the form of a table similar to the Statistics window described in the section "Statistics Window".

The **"Current Statistics"** option will produce a printout of the statistical calculations for the current experiment variable value. If the Statistics window is on the screen then a variable value and the corresponding data set will be the same as on Statistics window. If Statistics window has not been loaded, then the current variable value will be taken from the "All data" window.

The **"Averaged Results"** option will produce a printout of the averaged results of measurements for all variable values.

Select the printout option by clicking the mouse on the corresponding push-button in the group "Select Printout".

Enter the printout title into the title text box using the keyboard (up to 40 characters). This information will be printed on the top of your printout. If you check the boxes "Print Date" or/and "Print Time", the current date/time information will be printed at the right top corner of your printout.

Click OK to start printing.

Different kinds of printouts are shown in Appendix B.

7.4. Communication Setup Button

This command button is used to set up the system communication parameters when you run the program for the fist time or when you need to re-configure your system. If you click the mouse on this button, then the "Communication Setup" window will come up on the screen. Depending upon the type of the interface settings made earlier, you will see one of the three possible figures.

Fig. 9 - Fig. 11 present the different instances of the "Communication Setup" window. Fig. 9 shows the RS232 Setup window. Fig. 10 shows the MMR Splitter box Setup window. Fig. 11 shows the IEEE-488 Setup window.

Select the Interface type by clicking the corresponding button in the group located at the top of the "Communication Setup" window.

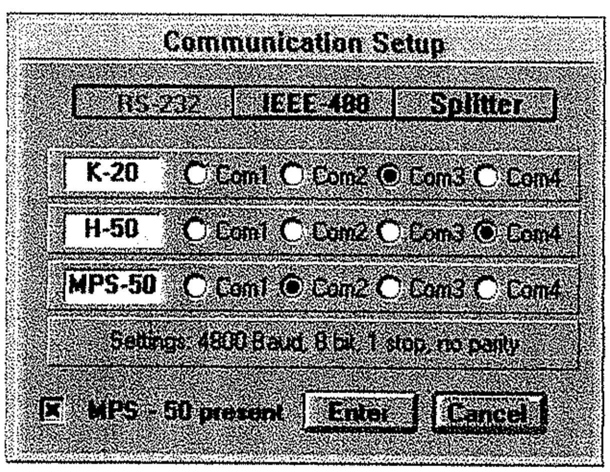


Fig. 9. RS-232 Setup window.

If you are going to use the MPS-50 Programmable Power Supply to control field, then click the mouse on the "MPS-50 Present" check box to make it "checked". If not, then uncheck this check box by another mouse click. In this case the MPS-50 communication settings will be excluded from the setup process.

If you use the RS-232 interface (Fig. 9) then you have to specify the COM port number for every controller. These numbers must match the hardware connections which we explained in the Section "Hardware setup". Select the COM port number for each controller by clicking the mouse on the corresponding option buttons. The COM port numbers for different controllers may not be the same.

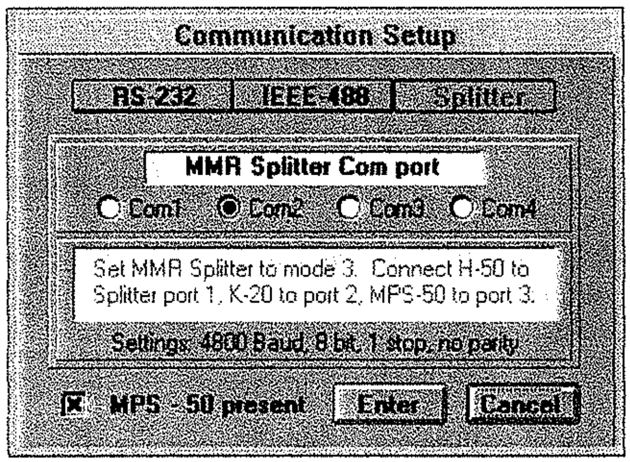


Fig. 10. Splitter Box Setup window.

If you use the MMR Splitter box (Fig. 10) then you have to specify the COM port number which is connected to the Splitter box. Click the mouse on the corresponding option button.

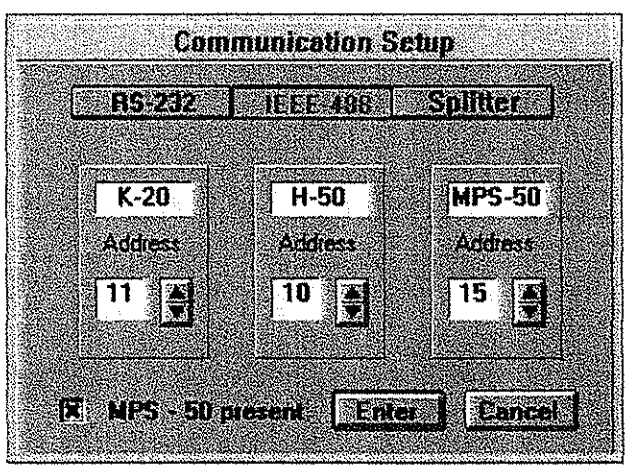


Fig. 11. IEEE-488 Setup window.

If you use the IEEE-488 interface (Fig. 11) then you have to set the IEEE-488 addresses for the controllers. These addresses must match the hardware address settings on the controllers' back panel (See Section 4, "Hardware Setup" and Controllers' Manuals). The address range is from 1 to 30. No two controllers may have the same addresses, and none of them may have address 21, which is reserved for the computer IEEE-488 unit.

Click OK button after all settings are completed.

7.5. Exit Program Button

This command button is used to exit the program. To initiate the command, click the mouse on the Exit button. The confirmation message box asking "OK to exit?" will appear on the screen. If you select "Yes" the program will be terminated.

If any unsaved collected data is present in your system then the corresponding reminder message box will appear. If you select "Yes" to save this data, then the Save File window will be loaded. The response "No" will terminate the program and all unsaved data will be lost.

You can also use the other Windows controls to terminate the program (such as double click on the control box or by using the "Close" command in the Program Manager). The exit procedure will stay the same.

7.6. K-20 Manual Control, H-50 Manual Control, MPS-50 Manual Control Buttons

These command buttons are used to provide interactive manual operation of the controllers. When you click one of these buttons, the corresponding control window will come up on the screen. All three of the windows are shown in Fig. 12. (See the following page.)

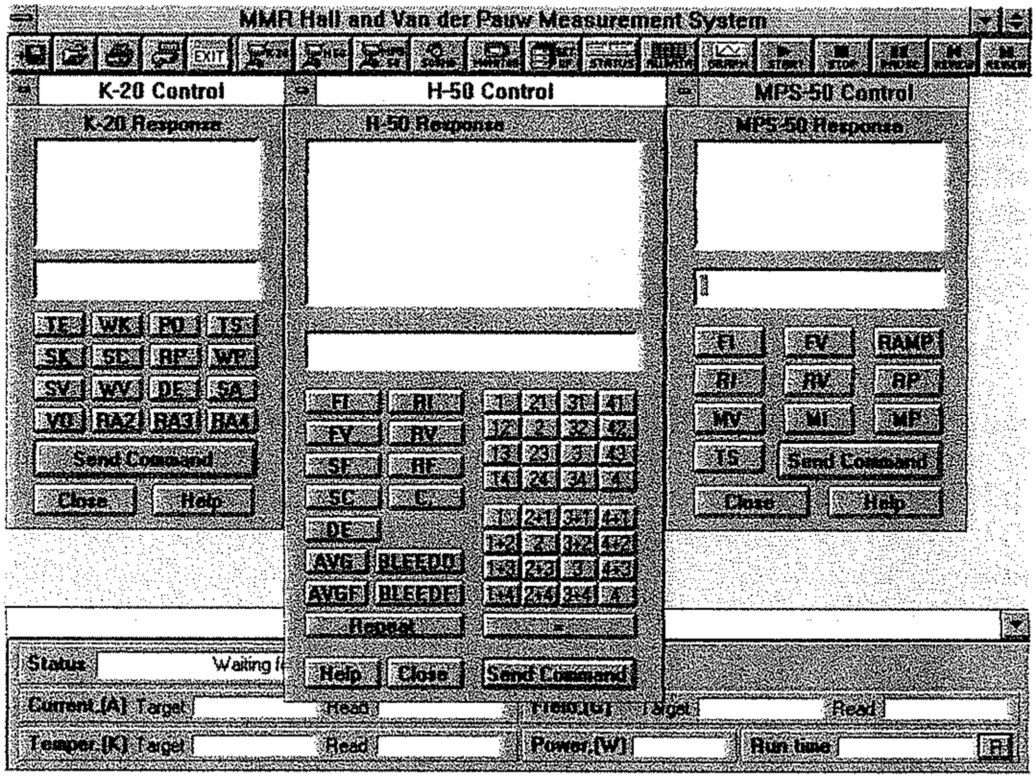


Fig. 12. Manual Control windows.

To send a command to the controller, click a command button on the Manual Control Window of this controller, and then click a button "Send Command" on the same window. You can also send the command by pressing "Enter" on the keyboard or by clicking the same command button for a second time.

For explanations of the commands' actions you may refer to each controllers' manual. You can also get a short description of the commands set by clicking the "Help" push-buttons which are present on every Manual Control window. These Help windows are shown in appendix A.

If the command to be sent requires a numerical parameter then you can enter this parameter into the command text box using the computer keyboard. To do so first click your mouse on the text box where you want to enter your data. Then type the data using keyboard. You can enter any command string using this method.

For the H-50, where the commands may require several parameters some the most common parameters can be entered by clicking the mouse on the corresponding parameter buttons. For example to send a command 'RV 12' you have to click "RV", "12" and "Send Command" buttons.

If you use the MMR Splitter box, then the first access to the H-50 controller may produce an error response. There is nothing wrong with this, it is just a characteristic of communication via the Splitter box. This situation is resolved when the System runs in the automatic regime.

The controller response will appear in the response text box.

To remove a Test window from the screen click "Exit" button on the Test window or double click the button in the control box.

7. 7 Sound On/Off Button

Clicking this button enables/disables system sounds. This button has two steady states. Sounds are enabled when button is down. Sounds are used when the system needs to attract the operator's attention:. when the alarm condition has occurred, when the experiment is complete, or a manual control action is required.

7.8 Temperature Monitor Button

Clicking this command button enables/disables the Temperature Monitoring function. The command button has two steady states. The Monitoring function is enabled when the push-button is down.

When the Temperature monitoring function is enabled, the program continuously collects data from the K-20 Temperature controller irrespective of the system status (See Section 9, "Experiment Run"). The Temperature and Power applied to the refrigerator are displayed on the System Status window inside the corresponding data panels.

When an experiment is in progress and the monitoring function is enabled, then these readings are being updated during the time data is being taken at the measurement point. If the monitoring function has been disabled, then the system displays the last Temperature and Power values which were read before taking data at the measurement point. The second regime is preferable, because it is faster. At the same time we assume that the temperature stability and accuracy provided by the K-20 are good enough to neglect the temperature fluctuations during the measurement if the temperature has stabilized.

7. 9 Experiment Setup Button

This command button is used to call the Experiment Setup window to the screen. Procedures on how to set up the experiment parameters will be described in Section 8, "Experiment Setup".

7.10 System Status Button

Clicking of this push-button brings to the screen the Status window if it is not already present (See Fig. 5). The System Status window is described in details in Section 9, "Experiment Run".

7.11 Display All Data Button

Clicking this command button presents the "Acquired Data" window on the screen. To activate this button, data has to be present in the system. If the data contains several data points then the clicking of the "Display All Data" button will also show a "Go to Data Point Number" window as shown in Fig. 13.

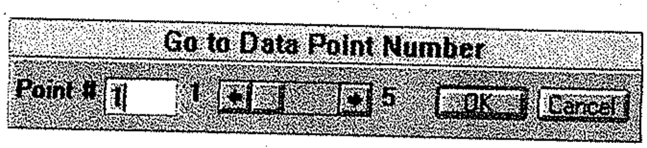


Fig. 13. "Go to Data Point Number" window.

This window gives you the opportunity to recall any data point for review by specifying its number. You can enter this number by using a scroll bar or by clicking the mouse on the "Point #" text box and then entering the point number using the keyboard. To display a selected point click the "OK" button. To close the window click "Cancel".

7.12 Graph Control Button

This command button is used to produce the graph output of the acquired data. We will explain how to create graphs in detail in Section 10, "Graphs".

7.13 Start Experiment, Stop Experiment, Pause Experiment Buttons

These three command buttons are used to control experiment flow.

To start Experiment click the "Start" button. If any unsaved data is present in your system, then a reminder message box will appear on the screen. If you elect to not save data, then all prior collected data will be lost. To start the experiment you have to set all experiment parameters first. If setup has not been done, then the system will remind you of this. You can check experiment parameters at any time by clicking the "Experiment Setup" button.

To pause experiment click "Pause" button. The caption of the button will change to "Restart". Click this button, if you want to continue the recording process. The recording will be continued from the last data point. When the System is in a "Pause" state (See "System Status window") you can change some, but not all, of the experiment parameters. When you click "Restart" the system will reset any changed experiment parameters and then continue to collect data.

To stop experiment click the "Stop" button.

7.14 Review Forward, Review Backward Buttons

These command buttons are used to change step by step the number of the data point which is presented in the "Acquired data" window. A click of the "Review forward" button increments the number of the data point to be displayed, the click of the "Review backward" button decrements the number.

To use these functions you have to have data in the system. If no data is present in the system, then these buttons will be disabled.

For Hall measurements each data point contains two data sets, so you can review both data sets sequentially by clicking these buttons.

Section 8. Experiment Setup

To display the Experiment Setup window you have to click the "Experiment Setup" button. The Experiment Setup window will come up as shown in Fig. 14.

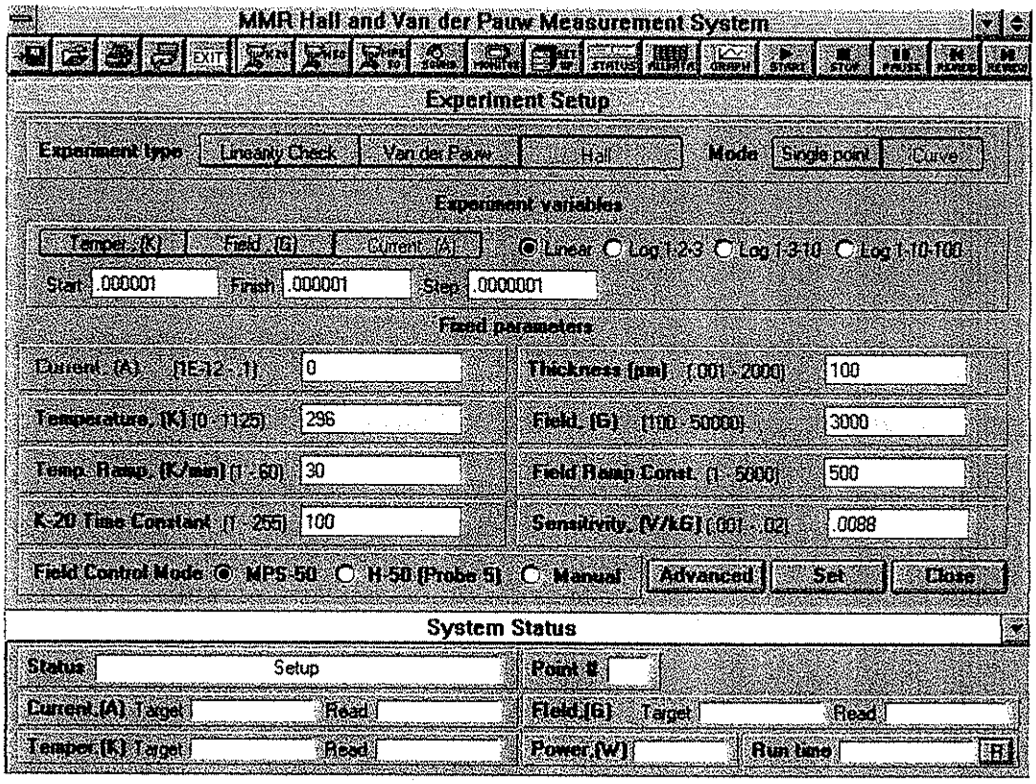


Fig. 14. Experiment Setup window.

8.1. Basic Setup

8.1.1. First you have to set the type and the mode of the experiment to run. To do so, click a control button in each of the groups "Experiment Type" and "Mode". There are three types of experiments which the system can manage: Linearity Check, Van der Pauw, and Hall Effect measurement.

The main purpose of the **Linearity Check** is to determine if the probes' electrical contacts with the studied sample are linear. In other words, to determine if Ohm's law is applicable. This experiment type is used as a preliminary check in advance of the Van der Pauw or Hall measurement. On the other hand, this experiment type can be used independently to study Voltage/Current characteristics.

The **Van der Pauw** measurement (Four probe resistivity measurement) produces the value(s) of the sample resistivity.

The **Hall Effect** measurement produces a set of parameters related to the Hall properties of the sample, such as Hall Coefficient, Mobility, Carriers Density, etc. Because the value of the sample resistivity is needed to calculate these parameters, the Hall Effect measurement includes the Van der Pauw resistivity measurement as the first step, followed by the Hall measurement itself.

There are two experiment modes: **Single Point** and **Curve**. The first mode is used when you have to measure the property(ies') value(s) under a certain set of conditions. The second mode is used when you want to study the property(ies') dependence versus an experiment variable.

8.1.2. If you have selected the Curve mode then you have to specify an **experiment variable** as the next step of the experiment setup. To do so, select the experiment variable by clicking a button on the Experiment variables panel. For the Single point mode the experiment variable does not make any sense, so in this mode the panel "Experiment Variables" will be disabled. There are some restrictions on the variables for the different types of experiments. For the Linearity Check, only the Current can be used as experiment variable, for the Van der Pauw measurement the Current and the Temperature can be used as experiment variables, and for the Hall measurement all three variables are available: the Current, the Temperature, and the Field.

8.1.3. After you have specified the Experiment Variable, you have to set the Start and Finish values of the variable. Then you have to set the formula specifying how the variable will change within the specified range. It can change in linear steps, or by the logarithmic law. There are three options of the logarithmic changes: 1-2-3 means that the variable has the values 1-2-3...9-10-20-30...90-100-200 etc.; 1-3-10 means the values 1-3-10-30-100-300 etc., and 1-10-100 option means order of magnitude steps. To select the way the variable is to change, click the mouse on the corresponding option button.

If you have selected "linear" steps, then the text box "Step" will appear on the panel and you will have to enter the Step value of the variable.

If you use Temperature as experiment variable, then you also have to set the Stand by temperature and enable/disable an option "Auto Go to Standby". If this option is enabled, the system will unconditionally attempt to set the Thermal Stage temperature to the Standby value after experiment has been completed. If this option is disabled, then the system will display the message box "Go to

Standby temperature? Yes /No" upon experiment completion, and the system proceeds according to your response.

8.1.4. The next step is the setup of the Fixed Parameters. There are eight Fixed parameters of the experiment which can be set: Current, Temperature, Temperature Ramp, K-20 Time Constant, Thickness (of the sample), Field, Field Ramp Constant, and Sensitivity (of the Hall sensor). The type of the experiment and choice of experiment variable govern any restrictions which may apply to the setup of the Fixed parameters. If a certain fixed parameter is irrelevant or unavailable for the given experiment type then the corresponding panel in the Fixed Parameters Group will be disabled. Some of the experiment parameters, such as Current, Temperature and Field may serve as experiment variables or as fixed parameters. So, if one of those parameters has been selected as the experiment variable, then it will be excluded from the list of fixed parameters and the corresponding panel will be disabled.

To set the value of the Fixed Parameter you have to click the mouse on the white text box which is located on the panel of the parameter to be set. Then, using the keyboard enter the required parameter value. You may use an arithmetic number or scientific number format. The range of the parameters' values as well as units are indicated on the fixed parameters' panels. **For the proper system operation you have to specify all enabled Fixed Parameters.**

8.1.5. The Hall measurement requires availability of a magnetic field. The possible ways for control of the field are discussed in Section 4, "Hardware Setup". There are three options to control the magnetic field. To select the desired option click the mouse on one of the option buttons on the panel "Field Control Mode". (See Fig. 14, Fixed Parameters Section.)

The first option is to use the **MPS-50** Programmable Power Supply. This option can be used only if the MPS-50 is present in your system. (See Section 7.4, "Communication Setup".) When this option is selected the system automatically controls the value of the magnetic field produced by the magnet M-50 powered by the MPS-50.

The next option is **H-50 (Probe-5) control**. This option means, that the system operates a third party power supply to produce the magnetic field. This Power supply is controlled by the H-50 controlling voltage on the Probe 5 of the H-50. This option requires that additional parameters be set. So, when you select this option the window "Field Control Setup" will come up as shown in Fig.15.

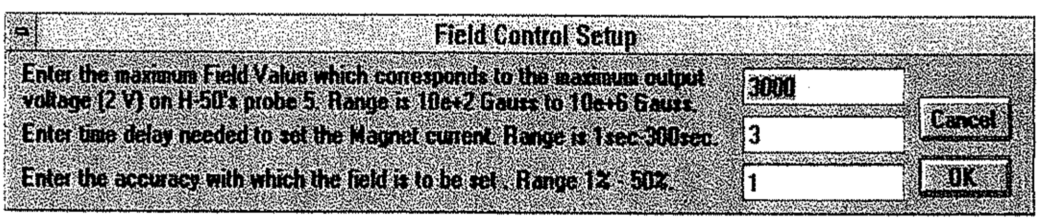


Fig. 15. Field Control Setup window.

In order to control the external power supply you have to specify the maximum field value which corresponds to the maximum control voltage (2 V) of the H-50's probe 5, the time delay needed to set Magnet current and field setting accuracy. The **maximum field value** is needed for the computer to calculate the first control voltage setting to provide the required Field value. After the system has measured the actual field the control voltage will be adjusted. This feedback loop will function until the required field value has been obtained. It takes time to change the current through the inductive load, so we have to introduce a **time delay** between the action which forces the current and the measurement of the field value. The system decides that the required field value has been reached when the difference between the actual and target values of the field is within the specified **accuracy**. You can set the Field Control Setup parameters using the same technique as for the Fixed Parameters. To make this settings effective, click the "OK" button.

The third Field Control Mode Option is **Manual control**. This means that every time the system needs to set the field to a certain value the system operator gets a corresponding message asking the operator to set the field. The required field value is then to be set by operator action.

There is one limitation to the system field control which is true for all of the field control options. The field measurements are taken by special Hall Sensor input to the H-50. The Maximum voltage which can be read at this input is 50 mV. So, the maximum field value, which can be measured (and therefore controlled) by the system can be defined as 50 mV divided by the Hall sensor sensitivity. For example, if the sensitivity is 10 mV/kG, then the maximum field which is readable is 5 kG. If you have specified a field value which exceeds the maximum you will get an error message. If you want to work with the larger fields, you will have to use Hall sensors with lower sensitivity.

Notice: The M-50 magnet is rated to provide 3500 gauss. Exceeding this limit will cause the magnet to heat up and performance to degrade.

8.1.6. After you have set all of the experiment parameters click the "Set" button. You will get the message "OK to use this settings". Click "OK". If you want to adjust any experiment parameter you can do it at any time. Just follow the instructions of this Section.

8.1.7. The system provides extensive monitoring of the setup data. This allows one to avoid problems when the experiment is in progress. If you get an error message after clicking the "Set" button, then correct the wrong value and click "Set" again.

8.1.8. The system saves the experiment setup in the file Hall.cfg upon exit of the program. This setup data will be retrieved when you next start the program.

8.1.9. You can close (or minimize) the Experiment Setup window by clicking the "Close" (or "Minimize") button.

8.2. Advanced Setup

For the sophisticated users the program offers several additional user defined parameters for fine tuning the measurement process. To access the advanced setup parameters click the "Advanced" push-button on the Experiment Setup window. The Advanced Setup window will come up on the screen as shown in Fig. 16.

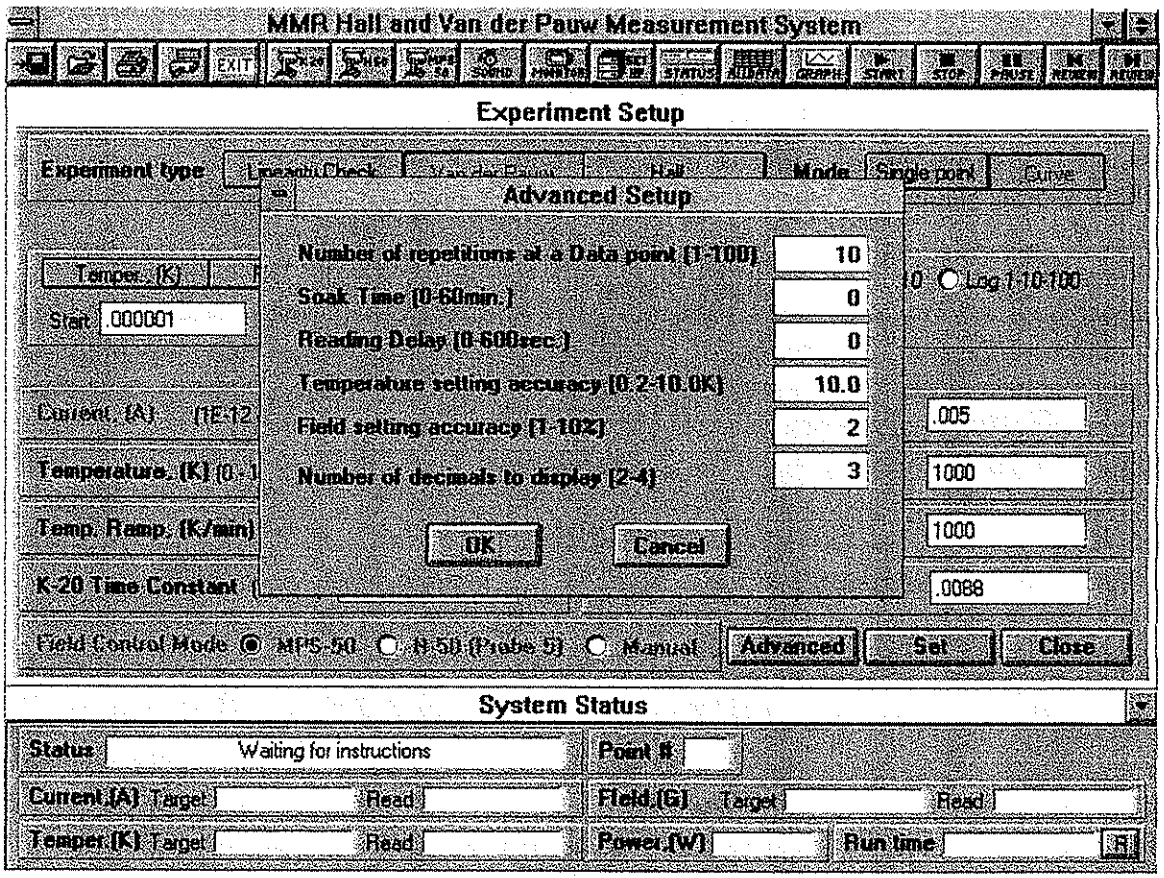


Fig. 16. Advanced Setup window.

The advanced setup includes the following parameters:

8.2.1. Number of repetitions at Data point. This setting defines how many times the system repeats the measurement at each data point. If you take more then one measurement then you may later apply statistical methods to interpret the acquired data. The default number is one, maximum number of repetitions is 100. Always check this number each time you set up an experiment.

8.2.2. Soak Time. The Soak time defines the time delay between the moment when the system has reached the set temperature and the moment the first data will be taken. This time is used to bring all the temperature related processes of the sample to the stable, equilibrium, state. Default time is 0, maximum Soak time is 60 min. When the experiment is running, progress through the Soak time delay will be indicated in the System Status window by a changing linear (bar) gauge.

8.2.3. Reading Delay. The Reading Delay defines the time delay between the moment when the system has applied measurement current to the sample and the moment the system reads the voltage. This delay may be useful for high impedance samples to bring all the electrical charging related processes to a stable state. Default time is 0, maximum Reading delay is 600 sec. One has to be very careful while setting the reading delay, because it dramatically increases the duration of the experiment. For example, if one has selected 10 seconds reading delay then for the Hall measurement this results in an increase of 160 seconds in the measurement time for each data point. When the experiment is running, progress through the Reading Delay will be indicated in the System Status window by a changing linear (bar) gauge.

8.2.4. Temperature setting Accuracy. During the temperature setting process the program decides if the target temperature has been set by taking several consecutive temperature readings. If all the collected temperature values are within a certain deviation window then the system makes the decision that the target temperature has been achieved. The Temperature Setting Accuracy defines this deviation. The standard Temperature Setting Accuracy for the system is 0.2 K, which is the system default. Under certain circumstances (very high temperatures, large thermal mass of the sample, additional probing tools attached to the sample, poor vacuum, etc.) the system may not keep up with the default accuracy and deviations may be increased up to 10 K.

8.2.5. Field setting accuracy. This parameter defines the accuracy of the field settings by the MPS-50. (If the Field is controlled by the H-50 then the similar setting is described in section 8.5). The system decides that the required field value has been reached when the difference between the actual and target values of the field are within the specified field setting accuracy. This Parameter is effective for the field values above 100 G, below this value an accuracy of 5 G is used. The Field Setting Accuracy may vary from 1 to 10%, default value is 2%. If one does not really need the high accuracy of the field settings, then increasing of this parameter will reduce the field setting time and reduce the experiment time as well.

8.2.6. Number of decimals to display. This number defines the format of the data which is presented in the Acquired Data window. This parameter determines how many digits are displayed to the right of the decimal separator. The parameter can have values from 2 to 4, default is 3.

To set a parameter, first click the right mouse button on the corresponding text box. Then using keyboard enter the value. After you have entered all settings click the "OK" push-button. You will get "Advanced Setup OK" message. If you have entered incorrect data, then a corresponding error message will appear on the screen.

Section 9. Experiment Run

9.1. Data Collecting Process

After you have completed the Experiment setup you can start the measurements. Click the button "Start". The "Acquired Data" window and the "System Status" window will come up as shown in Fig. 17. Every experiment step will be accompanied with the corresponding message on the Status panel in the System Status window.

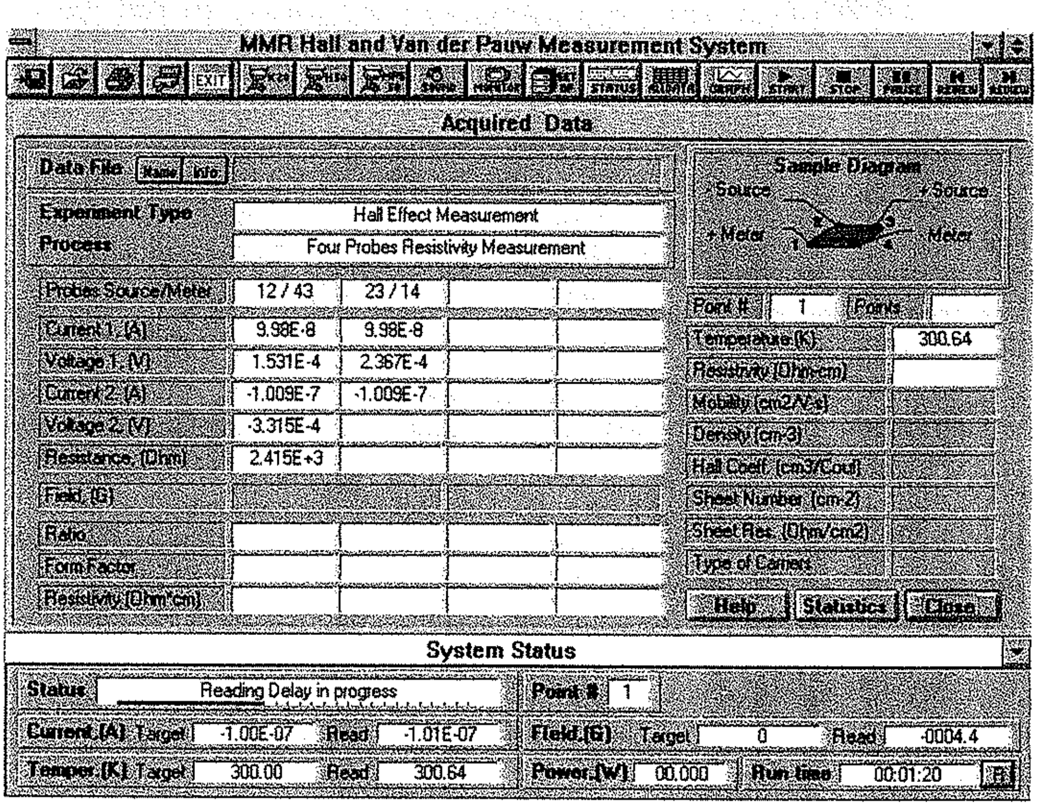


Fig. 17. The Acquired Data and System Status windows.

The experiment will begin with the setting up of the fixed parameters. You can monitor this process on the System Status window. When the fixed parameters have been set, then the system starts taking data if the experiment mode is "single point". If the experiment mode is "curve" then the system sets the start value of the experiment variable and then starts taking data once that value has been reached.

The wiring diagram of the current measurement is shown on the Sample Diagram panel in the top right corner of the Acquired Data window. For each configuration of probes, the system takes the data twice, once for each of two polarities of the forced current. This measure is used to eliminate any dc bias due to thermal voltage effects and other offsets. Each probe configuration has a corresponding column in the readings table (The configuration is indicated in the top cell of the column). The readings are placed in the table, one by one, until the measurement sequence has been completed. When the system has taken all the data for the current data point, it calculates the results and places these results into the appropriate cells of the table. The intermediate results which are related to a certain probe configuration are located in the same column as the readings for that probe configuration. The data point results are displayed in the table under the Sample Diagram.

The experiment type and the current measurement process are displayed on the corresponding panels of the Acquired Data window. The cells with a gray background color in the Acquired Data window are not supposed to be filled with data during the current experiment or measurement process.

The current point number and the number of processed data points are displayed in the panels under the Sample Diagram. You can also read the point number in the System Status Window. The System Status window presents the target and actually measured values of the Current, the Temperature and the Field, and the value of the Power which is being applied to the Thermal Stage Heater. This data, in conjunction with the system status messages, gives you a complete picture of the current system condition. If one or more parameters are not used by the current experiment then those parameter values will not be displayed. The System Status window also has a Run time timer, which starts at the moment you clicked the Start button. The small button with the caption "R" (Restart) located on the timer panel is used to restart the timer.

If you do not want to keep the Acquired Data window or System Status window on the screen while the experiment is in progress. You can minimize them by the clicking the "Close" button on the Acquired data window or minimize button on the System Status window (in the right top corner).

If you run the Hall measurements and control the field manually, then every time the system needs to set the field to a certain value you will get the Manual Field Control Window on the screen as shown in Fig. 18 (See the following page).

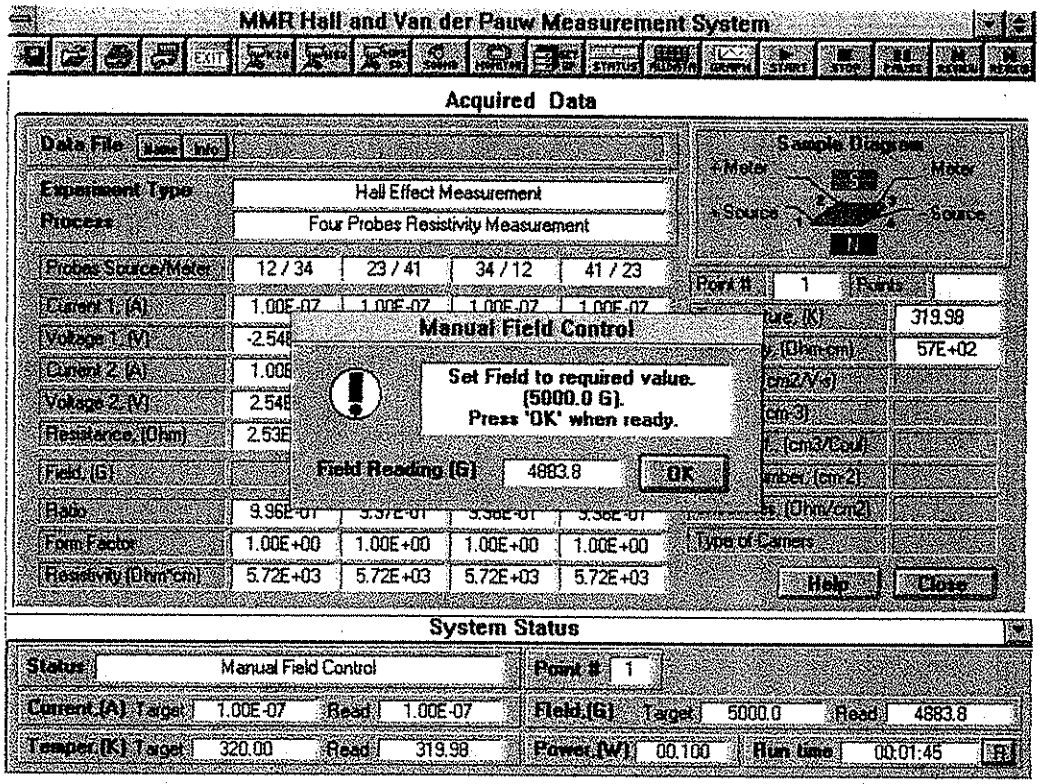


Fig. 18. Manual field control.

You have to set the source of the magnetic field to the required value. The actual field value will be continuously read and displayed in the Field Reading box. This data will be duplicated in the System Status window as the Read value of the Field. When you have obtained the required field reading, click "OK". The system will continue with the data acquisition process.

If you want to review the collected data or change experiment parameters and then continue the current experiment, you have to click the "Pause Experiment" button (See Section 6, "Getting Started"). To restart the experiment click the "Restart" button (The "Pause" button will change caption, once pushed).

When the experiment has been completed, the system produces a sound signal (if activated) and displays the corresponding system status. The operator may stop an experiment at any time by clicking the button "Stop Experiment". If, at this moment, the system has not completed the measurement sequence for the current data point then all the data collected for this point will be lost.

If the experiment variable is Temperature then the adjustment to the standby temperature setting will be initiated. If the option "Auto go to Standby" has been selected, then this process will start immediately after the experiment has stopped. Otherwise, the confirmation message will come up (See Section 8, "Experiment Setup") and the operator will have to provide instructions to the system on how to proceed.

The Data File panel in the Acquired data window stays gray when you collect data. This panel is enabled when you load the data file. Then this panel is used to display the name of the loaded file and the file information string (See Sections 7.1,"Save File" and 7.2 "Load File"). You have to click the button "Name" or "Info" to obtain the required data.

When an experiment is in progress and you have collected data for two or more data points you can have the results displayed in the form of a graph. This graph will be updated with each additional data point as it is collected. We explain in detail how to set this feature in Section 10, "Graphs".

9.2. Formula Reference

To see the formulas which are used in the calculation of the results click the "Help" button. The Help window will come up as shown in Fig. 19. Click "Close" to remove the Help window.

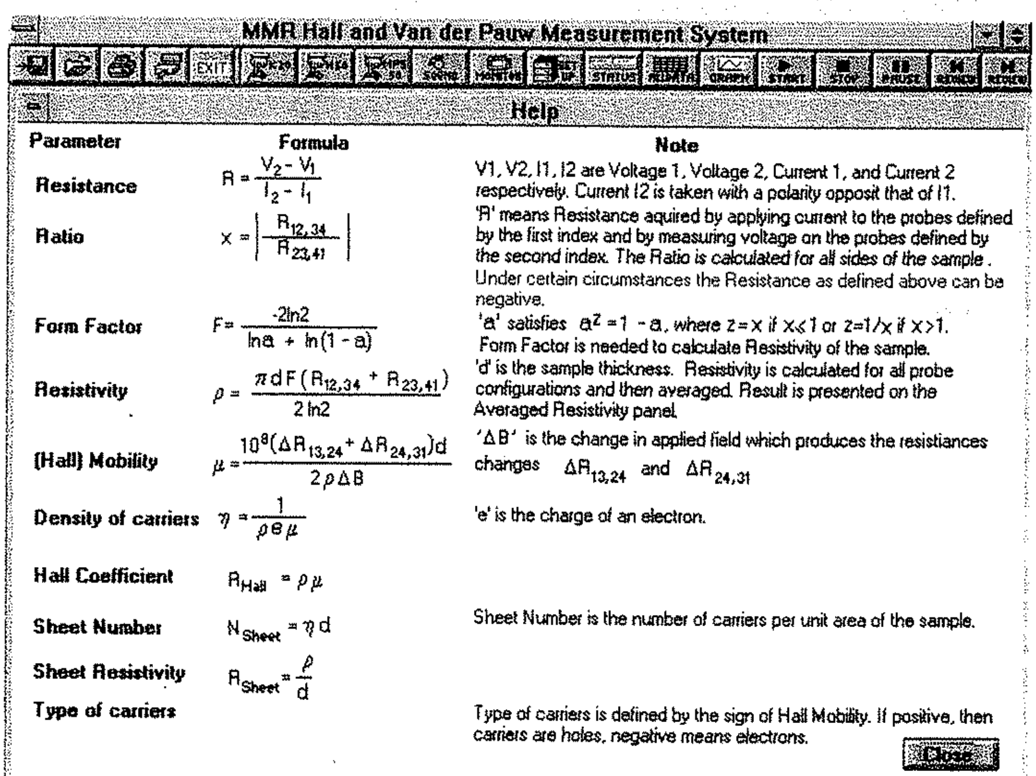


Fig. 19. Help window.

9.3. Statistics Window

If several data points have been taken for each experiment variable value (See section "Advanced Setup"), then the program can calculate statistical data of those readings. To obtain statistics one has to click the push-button "Statistics" on the "Acquired Data" window. The Statistics window will appear on the screen as shown in Fig. 20. One can open the Statistics window when the experiment is in progress, as well as when the experiment has been stopped or paused or a data file has been loaded. The push-button "Statistics" will be disabled if the experiment is of Linearity check type or if the loaded data file has been created by earlier versions of the program and does not contain statistics data. A corresponding message will come up during the loading of the data file of old (earlier software version) type.

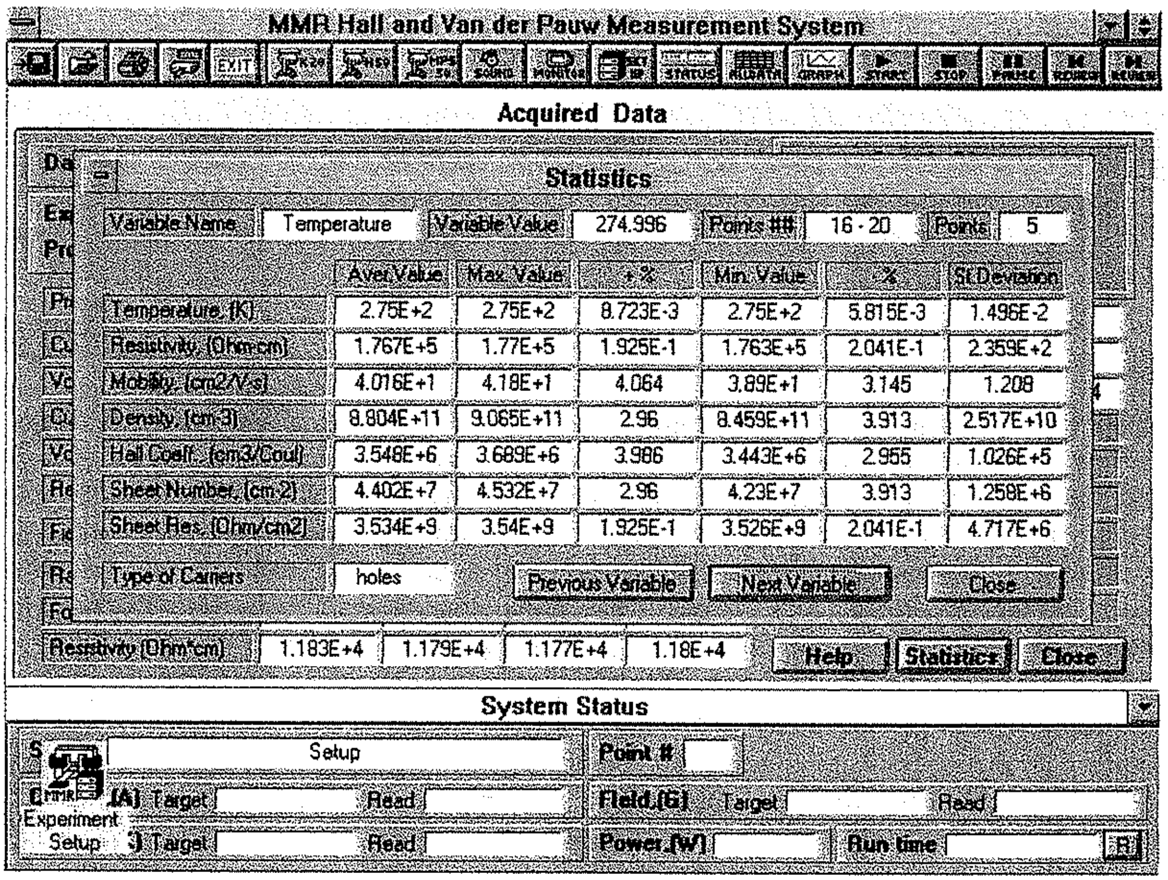


Fig.20. Statistics window.

Statistics window displays the following set of statistical data of each result for the given value of experiment variable:

- Averaged value;
- Maximum value;
- +% - Deviation of the Maximum value from the Averaged value in percent;
- Minimum value;
- -% Deviation of the Minimum value from the Averaged value in percent;
- Standard deviation.

The first row on the window contains the name and the value of experiment variable as well as numbers and quantity of data points that have been collected at this variable value.

Notice: If calculated results for the different data points at the same variable value identify different types of carriers, then the Type of carriers box will indicate "?".

To obtain the statistical data for the previous or next variable value click push-buttons "Next Variable" or "Previous Variable" respectively.

To close the Statistics window, click "Close".

9.4. Auto Backup

The program has an automated backup feature. It creates the backup.h50 data file in the working directory every time the user starts a new experiment. This new file overwrites the old one with the same name that was created during the previous experiment. The program updates this file with every collected data point. This feature gives the user an opportunity to recover the collected data if the measurement system failed during the experiment run. To do so the user has to restore the program to normal function (this may require the operator to reset the computer and to restart the program), then open the backup.h50 file and save it under the different name (See Sections 7.1, "Save File" and 7.2, "Load File"). This also can be done using the File Manager. The backup.h50 file will contain all the data collected before the failure, and only the last data point will be lost.

Notice: Do not start a new experiment before you recover the data from the previous, interrupted, experiment, otherwise you will loose it!

Section 10. Graphs

Acquired data can be presented in the form of graphs. The program includes powerful graphical data presentation tools. To build graphs the system has to collect at least two data points. Obviously, graph can not be produced in a single point experiment regime.

If you want to configure a graph click the "Graph Control" button. The Plot Setup window will be displayed at the bottom of the screen as shown in Fig. 21. This window presents the controls for selecting parameters to produce graph, graph type, X and Y scaling, and turning on/off grid lines.

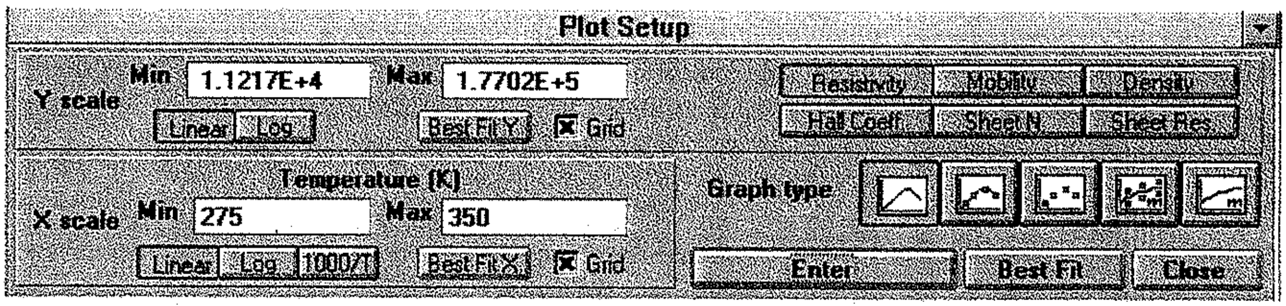


Fig. 21. Plot Setup window.

Notice: All settings or setting changes become effective <u>only</u> after clicking the "Enter" button.

In the Plot Setup window you will see two panels containing a set of controls related to scales X and Y respectively. The Y scale panel gives you a choice of parameters (experiment results) to be plotted. To select a parameter you have to click the corresponding button (up right corner of the Plot setup window). Different types of experiments presume a different set of available graphs. For the Linearity check you can plot the resistance for four probes configurations (each separately or all together); for the Van der Pauw measurement you can plot the Resistivity; for the Hall measurement you can plot graphs of Resistivity, Mobility, Density, Hall Coefficient, Sheet Number, and Sheet Resistivity. The X scale of the graph is the Experiment Variable.

For both scales you can set the high and low scale limits. Click the mouse on the text box of the scale limit. Then enter the scale limit value using the keyboard.

Notice: The system provides an automatic intelligent scaling feature. This means, that the limit values you have entered will be rounded to produce the actual scale limits and the scale ticks will be placed in a way to provide optimal readability of the graph.

When you click the "Best Fit" button (in "Graph Type" window), the system sets both the X and Y scales to produce the optimum graph presentation. If you want to automatically zoom to part of a graph, then you can use the "Best Fit X" and/or "Best Fit Y" buttons. For example, you want to zoom the Y scale for the range of X values starting from X1 to X2. First enter the limits X1 and X2 on the X scale panel. Then click the "Best Fit Y" button. The resulting graph will have the X scale starting at X1 and ending at X2 (see note above), and the Y scale will be set for the optimal data presentation within the specified X scale range. The "Best Fit X" button operates similarly, except you have to define the Y scale range first. If you are not satisfied with the appearance of the graph (for example, some data points can be located out of scale limits), you may try to click Best Fit buttons for the second time. This can enhance your picture because the system uses two different criterias to calculate best fit limits. The system switches the criterias with every click.

For both the X and Y scales you can use linear and logarithmic modes as well. To select the required mode click the buttons "Linear" or "Log" on the scales' panels. You may not use the logarithmic scales if the set of parameters values to be plotted contains zero or negative values. Non positive scale limits for the logarithmic scale will result in an error message.

If the experiment variable is the temperature, the system provides an extra plotting feature. You can format the X-scale not only in absolute temperature values, but also in values of 1000/T (T is the absolute temperature). This format is more convenient for the presentation of the certain kinds of curves. To set this format click the "1000/T" button on the X-scale panel.

You can turn on/off grid lines for X and Y scales separately. To do so click the mouse on the check boxes "Grid". If the check box has the status "checked", then the corresponding grid lines will be displayed.

The next step is selecting type of graph. There are five types of graph: line, line with data point marks, scatter, scatter with mean line, and mean line only. To select the graph type click the corresponding graph type push-button. The icons on those buttons show the graph's "look". The graph types involving mean values are not available for the Linearity Check. If the data file does not contain statistics data then the corresponding warning message will come up when an attempt is made to request a mean graph. The cross symbols on the mean curves (blue color) show the position of the calculated mean value.

After all settings have been completed press the button "Enter" to produce the graph image. The Data Curve window will come up as shown in Fig. 22.

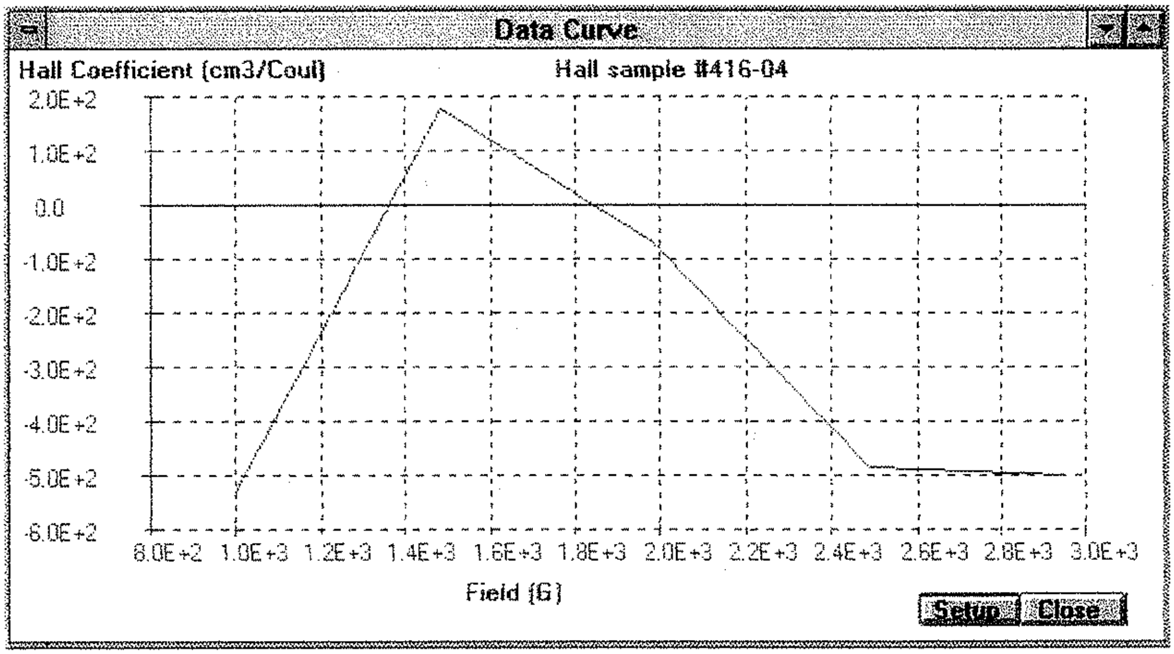


Fig. 22. Data Curve window.

To make any changes to your graph use the controls on the Plot Setup window. To make these changes effective press "Enter".

If you have used best fit features and receive an error message like "Can not calculate best fit limits" this can be explained by the following. If no curve data points exist within the specified range of scale then the system can not define the high and low scale limits. If you get this message then you have to enter scale limits yourself. You should also keep in mind, that the scaling capabilities of the system are limited to four digits. If you have entered the low scale limit as 1.2347 and the high scale limit as 1.2348 and click "Enter" then the scaling function will round both values to 1.235 and you will get the message like "Scale high limit must be less then low limit". This message can also occur after you have used the best fit functions if the curve to be plotted is flat with the four digits accuracy (or have the equal values). To resolve the problem you have to re-adjust the scale limits.

If you plot several data points at one value of experiment variable, then the auto scaling function is unable to set X-scale limits. If you press Enter you will get an error message "X Scale high limit must be less then low limit". To fix the problem you can reduce the low limit, or increase the high limit, or do both and then press Enter again.

You can move, resize, and maximize the Data Curve window using regular windows techniques. To recall the Plot Setup window click the button "Setup" on the Data Curve window. To close the Data Curve window click the "Close" button. The Plot Setup window and the Data Plot window will have to be closed before you can load a new data file or start a new experiment.

You can produce a hard copy of the graph image. To do so you have to build the graph first. For details see Section 7.3, "Print".

The graph can be built while the experiment is in progress. If the system has collected two or more data points you can enable the graph in the same way as described above. The subsequent data points will be added automatically to the graph.

In the case of plotting the results of the Linearity Check you may select the graph "All four curves" then the four curves of resistance versus current for different probe configurations will be displayed as shown in Fig. 23. The curves will have different colors. The color code is shown in the legend of the Y-scale. In the printout these curves are coded using the different curve data point symbols.

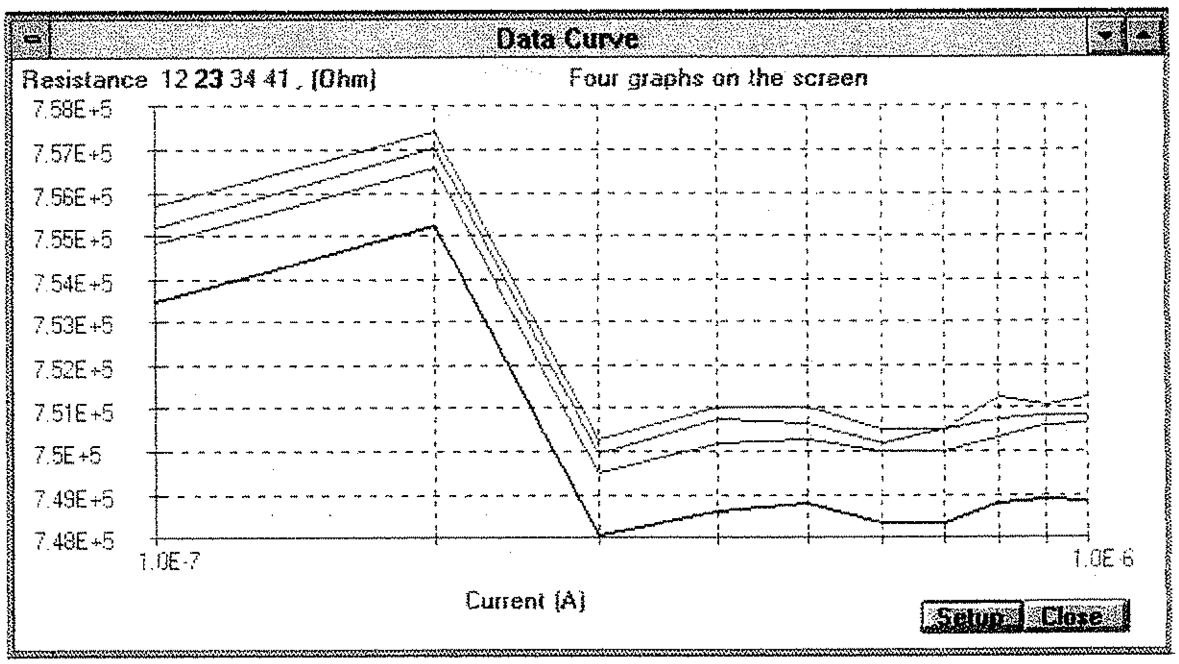


Fig. 23. Data Curve window with four graphs.

Section 11. Program Operating Notes

11.1. The program can successfully run on the foreground and background as well in maximized, normal or minimized windows status.

11.2. The program windows can be minimized and the corresponding icons will be present at the bottom of the main window (See Fig. 24).

Fig. 24. Icons of minimized program windows.

Section 12. Customer Support

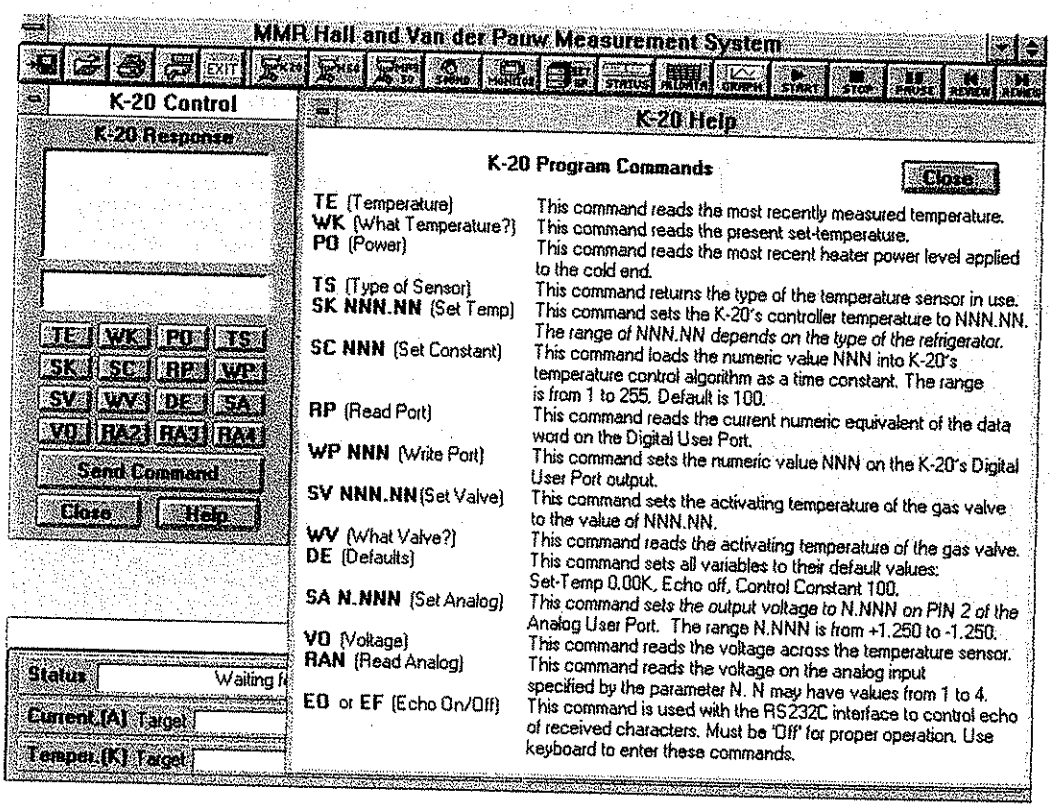
MMR Technologies provides customer support and upgrade of the supplied software products. You can call (415) 962-9620 or send fax (415) 962-9647 on business days from 8 am to 5 p.m. Pacific Time.

Section 13. Warranty

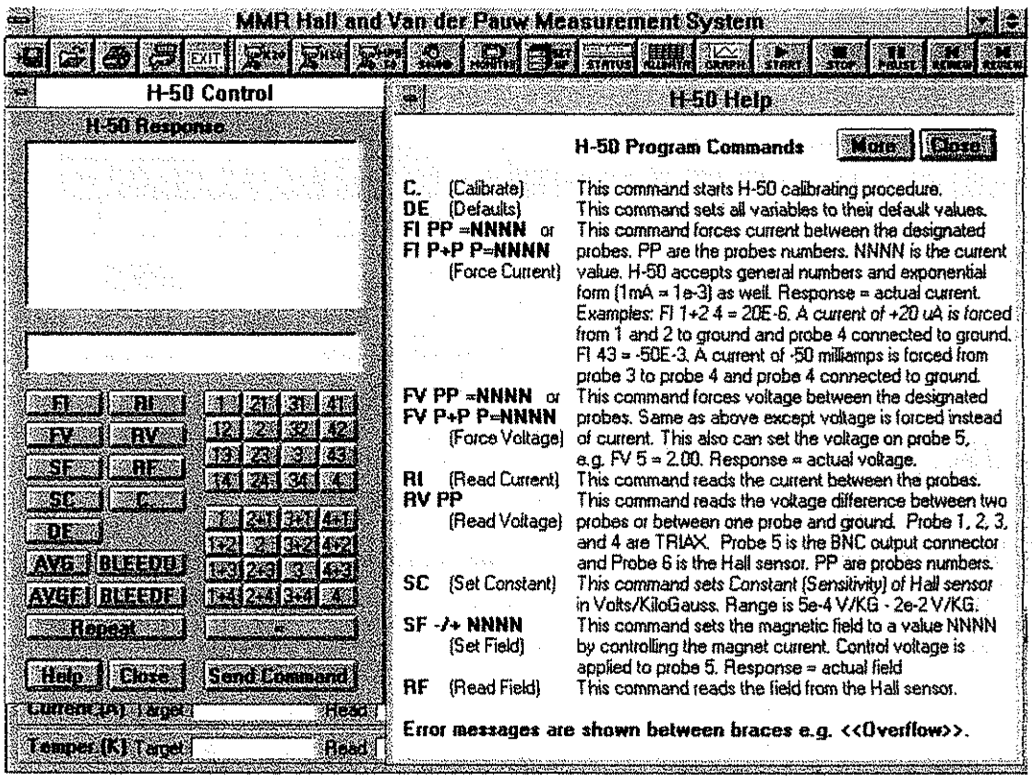
MMR Technologies, Inc. warrants its product, classified as "Hall and Van der Pauw Measurement System Software", against all defects in material and workmanship to the original using purchaser for a period of one (1) year from the date of shipment by MMR. During the warranty period, MMR will repair or replace, at its option, any equipment found to be defective in material or workmanship. Merchandise must be returned freight prepaid for warranty service to: MMR Technologies, Inc., 1400 North Shoreline Blvd., Suite A-5, Mountain View, CA 94043-1346. MMR's liability under this warranty is limited to the cost of repair or replacement of the product. This warranty does not extend to damage resulting from alteration, misuse, negligence or abuse, normal wear and tear, or accident. Expendable items are not included in this warranty. IN NO EVENT SHALL MMR BE LIABLE FOR INCIDENTAL OR CONSEQUENTIAL DAMAGES, EVEN IF MMR HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES. THERE ARE NO IMPLIED WARRANTIES OF MERCHANTABILITY, OF FITNESS FOR A PARTICULAR USE, OR OF ANY NATURE.

Appendix A. Commands Help Windows

A.1. K-20 Commands Help Window



A.2. H-50 Commands Help Window



MMR Hall and Van der Pauw Measurement System

JCG3P004 300K-600K 7.5mT 3030G 1mA

Hall Effect Measurement

Fixed Parameters:

Temperature Ramp (K/min)	30
Field (G)	3030
Field Ramp Const.	500
Sensitivity (V/kG)	.00942
Thickness (microns)	.304
K20 Time Constant	100
Current (A)	.001
Number Of Data Points	75

Advanced Parameters:

Number of repetitions	6
Soak Time (min.)	10
Reading Delay (sec.)	3
Temperature setting accuracy (K)	4
Field setting accuracy (%)	1

#	Temperature (K)	Resistivity (Ohm*cm)	Mobility (cm2/Vs)	Density (cm-3)	Hall Coeff. (cm3/Coul)	Sheet N (cm-2)	Sheet R (Ohm/cm2)	Carriers
1	300	4.237E-04	-25.40083	-5.800E+20	-5.381E-03	-1.763E+16	13.93756	electrons
2	300	4.238E-04	-26.43605	-5.572E+20	-5.601E-03	-1.694E+16	13.93926	electrons
3	300	4.238E-04	-25.539	-5.768E+20	-5.411E-03	-1.753E+16	13.94017	electrons
4	300	4.237E-04	-27.7044	-5.317E+20	-5.870E-03	-1.616E+16	13.93896	electrons
5	300	4.238E-04	-28.22956	-5.217E+20	-5.982E-03	-1.586E+16	13.94183	electrons
6	300.04	4.239E-04	-26.02851	-5.657E+20	-5.517E-03	-1.720E+16	13.94507	electrons
7	325	4.297E-04	-25.70244	-5.651E+20	-5.523E-03	-1.718E+16	14.13626	electrons
8	325	4.300E-04	-27.31941	-5.314E+20	-5.873E-03	-1.615E+16	14.144	electrons
9	325	4.302E-04	-25.05146	-5.792E+20	-5.388E-03	-1.761E+16	14.15106	electrons
10	325	4.303E-04	-24.95021	-5.815E+20	-5.368E-03	-1.768E+16	14.15348	electrons
11	325	4.304E-04	-27.12374	-5.347E+20	-5.837E-03	-1.626E+16	14.15777	electrons
12	325	4.304E-04	-25.92406	-5.595E+20	-5.579E-03	-1.701E+16	14.15767	electrons
13	350	4.357E-04	-23.56718	-6.080E+20	-5.134E-03	-1.848E+16	14.33088	electrons
14	350	4.356E-04	-24.2216	-5.916E+20	-5.276E-03	-1.798E+16	14.32977	electrons
15	349.98	4.355E-04	-28.91104	-4.957E+20	-6.296E-03	-1.507E+16	14.32723	electrons
16	349.98	4.357E-04	-29.78519	-4.810E+20	-6.489E-03	-1.462E+16	14.33365	electrons
17	350	4.358E-04	-24.67211	-5.806E+20	-5.376E-03	-1.765E+16	14.33502	electrons
18	350	4.360E-04	-26.59573	-5.383E+20	-5.798E-03	-1.637E+16	14.34146	electrons
19	375	4.419E-04	-27.81891	-5.077E+20	-6.147E-03	-1.544E+16	14.5374	electrons
20	375.02	4.420E-04	-27.76075	-5.088E+20	-6.134E-03	-1.547E+16	14.5379	electrons
21	375	4.420E-04	-26.44846	-5.339E+20	-5.846E-03	-1.623E+16	14.54091	electrons
22	374.98	4.421E-04	-26.14084	-5.401E+20	-5.778E-03	-1.642E+16	14.5427	electrons
23	374.98	4.421E-04	-26.66226	-5.295E+20	-5.894E-03	-1.610E+16	14.54418	electrons
24	375.02	4.420E-04	-24.85666	-5.681E+20	-5.494E-03	-1.727E+16	14.5407	electrons
25	400	4.493E-04	-25.55642	-5.436E+20	-5.742E-03	-1.653E+16	14.78052	electrons
26	400	4.493E-04	-27.49694	-5.053E+20	-6.177E-03	-1.536E+16	14.77926	electrons
27	400.02	4.491E-04	-23.72803	-5.858E+20	-5.328E-03	-1.781E+16	14.77166	electrons
28	400.02	4.492E-04	-25.61597	-5.425E+20	-5.753E-03	-1.649E+16	14.77612	electrons
29	400.04	4.492E-04	-30.82379	-4.509E+20	-6.922E-03	-1.371E+16	14.77511	electrons
30	400	4.490E-04	-27.09117	-5.131E+20	-6.082E-03	-1.560E+16	14.77077	electrons
31	425	4.553E-04	-29.76147	-4.606E+20	-6.776E-03	-1.400E+16	14.97787	electrons
32	424.98	4.550E-04	-25.7451	-5.329E+20	-5.857E-03	-1.620E+16	14.96724	electrons
33	425	4.551E-04	-27.46503	-4.994E+20	-6.250E-03	-1.518E+16	14.97048	electrons
34	424.98	4.547E-04	-25.56999	-5.369E+20	-5.813E-03	-1.632E+16	14.95634	electrons
35	425.02	4.543E-04	-24.77272	-5.547E+20	-5.627E-03	-1.686E+16	14.94393	electrons
36	425.02	4.546E-04	-27.18676	-5.051E+20	-6.179E-03	-1.536E+16	14.95244	electrons

MMR Hall and Van der Pauw Measurement System

JCG3P004 300K-600K 7.5mT 3030G 1mA

Hall Effect Measurement

Fixed Parameters:

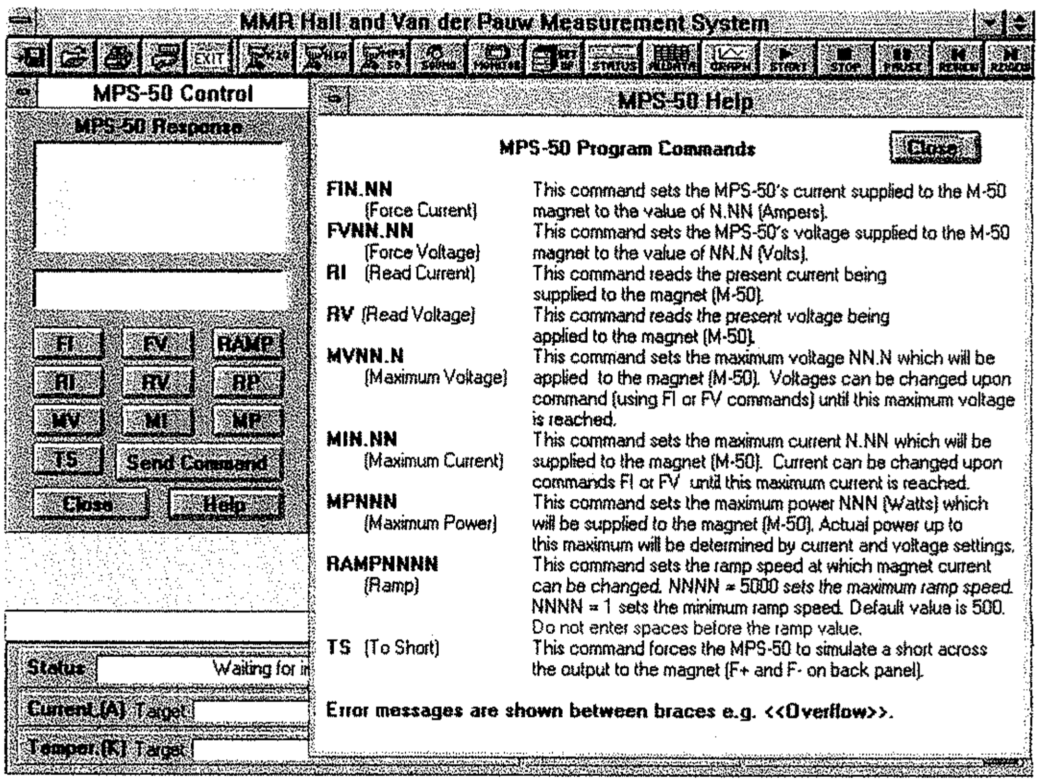
Temperature Ramp (K/min)	30
Field (G)	3030
Field Ramp Const.	500
Sensitivity (V/kG)	.00942
Thickness (microns)	.304
K20 Time Constant	100
Current (A)	.001
Number Of Data Points	75

Advanced Parameters:

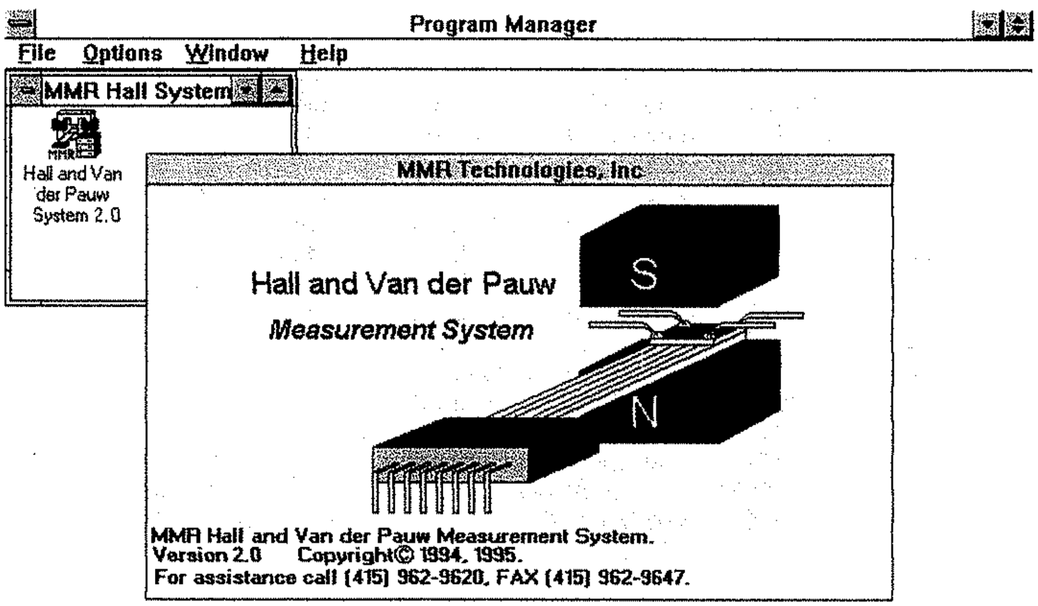
Number of repetitions	6
Soak Time (min.)	10
Reading Delay (sec.)	3
Temperature setting accuracy (K)	4
Field setting accuracy (%)	1

#	Temperature (K)	Resistivity (Ohm*cm)	Mobility (cm2/Vs)	Density (cm-3)	Hall Coeff. (cm3/Coul)	Sheet N (cm-2)	Sheet R (Ohm/cm2)	Carriers
1	300	4.237E-04	-25.40083	-5.800E+20	-5.381E-03	-1.763E+16	13.93756	electrons
2	300	4.238E-04	-26.43605	-5.572E+20	-5.601E-03	-1.694E+16	13.93926	electrons
3	300	4.238E-04	-25.539	-5.768E+20	-5.411E-03	-1.753E+16	13.94017	electrons
4	300	4.237E-04	-27.7044	-5.317E+20	-5.870E-03	-1.616E+16	13.93896	electrons
5	300	4.238E-04	-28.22956	-5.217E+20	-5.982E-03	-1.586E+16	13.94183	electrons
6	300.04	4.239E-04	-26.02851	-5.657E+20	-5.517E-03	-1.720E+16	13.94507	electrons
7	325	4.297E-04	-25.70244	-5.651E+20	-5.523E-03	-1.718E+16	14.13626	electrons
8	325	4.300E-04	-27.31941	-5.314E+20	-5.873E-03	-1.615E+16	14.144	electrons
9	325	4.302E-04	-25.05146	-5.792E+20	-5.388E-03	-1.761E+16	14.15106	electrons
10	325	4.303E-04	-24.95021	-5.815E+20	-5.368E-03	-1.768E+16	14.15348	electrons
11	325	4.304E-04	-27.12374	-5.347E+20	-5.837E-03	-1.626E+16	14.15777	electrons
12	325	4.304E-04	-25.92406	-5.595E+20	-5.579E-03	-1.701E+16	14.15767	electrons
13	350	4.357E-04	-23.56718	-6.080E+20	-5.134E-03	-1.848E+16	14.33088	electrons
14	350	4.356E-04	-24.2216	-5.916E+20	-5.276E-03	-1.798E+16	14.32977	electrons
15	349.98	4.355E-04	-28.91104	-4.957E+20	-6.296E-03	-1.507E+16	14.32723	electrons
16	349.98	4.357E-04	-29.78519	-4.810E+20	-6.489E-03	-1.462E+16	14.33365	electrons
17	350	4.358E-04	-24.67211	-5.806E+20	-5.376E-03	-1.765E+16	14.33502	electrons
18	350	4.360E-04	-26.59573	-5.383E+20	-5.798E-03	-1.637E+16	14.34146	electrons
19	375	4.419E-04	-27.81891	-5.077E+20	-6.147E-03	-1.544E+16	14.5374	electrons
20	375.02	4.420E-04	-27.76075	-5.088E+20	-6.134E-03	-1.547E+16	14.5379	electrons
21	375	4.420E-04	-26.44846	-5.339E+20	-5.846E-03	-1.623E+16	14.54091	electrons
22	374.98	4.421E-04	-26.14084	-5.401E+20	-5.778E-03	-1.642E+16	14.5427	electrons
23	374.98	4.421E-04	-26.66226	-5.295E+20	-5.894E-03	-1.610E+16	14.54418	electrons
24	375.02	4.420E-04	-24.85666	-5.681E+20	-5.494E-03	-1.727E+16	14.5407	electrons
25	400	4.493E-04	-25.55642	-5.436E+20	-5.742E-03	-1.653E+16	14.78052	electrons
26	400	4.493E-04	-27.49694	-5.053E+20	-6.177E-03	-1.536E+16	14.77926	electrons
27	400.02	4.491E-04	-23.72803	-5.858E+20	-5.328E-03	-1.781E+16	14.77166	electrons
28	400.02	4.492E-04	-25.61597	-5.425E+20	-5.753E-03	-1.649E+16	14.77612	electrons
29	400.04	4.492E-04	-30.82379	-4.509E+20	-6.922E-03	-1.371E+16	14.77511	electrons
30	400	4.490E-04	-27.09117	-5.131E+20	-6.082E-03	-1.560E+16	14.77077	electrons
31	425	4.553E-04	-29.76147	-4.606E+20	-6.776E-03	-1.400E+16	14.97787	electrons
32	424.98	4.550E-04	-25.7451	-5.329E+20	-5.857E-03	-1.620E+16	14.96724	electrons
33	425	4.551E-04	-27.46503	-4.994E+20	-6.250E-03	-1.518E+16	14.97048	electrons
34	424.98	4.547E-04	-25.56999	-5.369E+20	-5.813E-03	-1.632E+16	14.95634	electrons
35	425.02	4.543E-04	-24.77272	-5.547E+20	-5.627E-03	-1.686E+16	14.94393	electrons
36	425.02	4.546E-04	-27.18676	-5.051E+20	-6.179E-03	-1.536E+16	14.95244	electrons

A.3. MPS-50 Commands Help Window



Appendix B. Printout Examples



MMR Hall and Van der Pauw Measurement System

JCG3P004 300K-600K 7.5mT 3030G 1mA

Hall Effect Measurement

Fixed Parameters:

Temperature Ramp (K/min)	30
Field (G)	3030
Field Ramp Const.	500
Sensitivity (V/kG)	.00942
Thickness (microns)	.304
K20 Time Constant	100
Current (A)	.001
Number Of Data Points	75

Advanced Parameters:

Number of repetitions	6
Soak Time (min.)	10
Reading Delay (sec.)	3
Temperature setting accuracy (K)	4
Field setting accuracy (%)	1

#	Temperature (K)	Resistivity (Ohm*cm)	Mobility (cm2/Vs)	Density (cm-3)	Hall Coeff. (cm3/Coul)	Sheet N (cm-2)	Sheet R (Ohm/cm2)	Carriers
1	300	4.237E-04	-25.40083	-5.800E+20	-5.381E-03	-1.763E+16	13.93756	electrons
2	300	4.238E-04	-26.43605	-5.572E+20	-5.601E-03	-1.694E+16	13.93926	electrons
3	300	4.238E-04	-25.539	-5.768E+20	-5.411E-03	-1.753E+16	13.94017	electrons
4	300	4.237E-04	-27.7044	-5.317E+20	-5.870E-03	-1.616E+16	13.93896	electrons
5	300	4.238E-04	-28.22956	-5.217E+20	-5.982E-03	-1.586E+16	13.94183	electrons
6	300.04	4.239E-04	-26.02851	-5.657E+20	-5.517E-03	-1.720E+16	13.94507	electrons
7	325	4.297E-04	-25.70244	-5.651E+20	-5.523E-03	-1.718E+16	14.13626	electrons
8	325	4.300E-04	-27.31941	-5.314E+20	-5.873E-03	-1.615E+16	14.144	electrons
9	325	4.302E-04	-25.05146	-5.792E+20	-5.388E-03	-1.761E+16	14.15106	electrons
10	325	4.303E-04	-24.95021	-5.815E+20	-5.368E-03	-1.768E+16	14.15348	electrons
11	325	4.304E-04	-27.12374	-5.347E+20	-5.837E-03	-1.626E+16	14.15777	electrons
12	325	4.304E-04	-25.92406	-5.595E+20	-5.579E-03	-1.701E+16	14.15767	electrons
13	350	4.357E-04	-23.56718	-6.080E+20	-5.134E-03	-1.848E+16	14.33088	electrons
14	350	4.356E-04	-24.2216	-5.916E+20	-5.276E-03	-1.798E+16	14.32977	electrons
15	349.98	4.355E-04	-28.91104	-4.957E+20	-6.296E-03	-1.507E+16	14.32723	electrons
16	349.98	4.357E-04	-29.78519	-4.810E+20	-6.489E-03	-1.462E+16	14.33365	electrons
17	350	4.358E-04	-24.67211	-5.806E+20	-5.376E-03	-1.765E+16	14.33502	electrons
18	350	4.360E-04	-26.59573	-5.383E+20	-5.798E-03	-1.637E+16	14.34146	electrons
19	375	4.419E-04	-27.81891	-5.077E+20	-6.147E-03	-1.544E+16	14.5374	electrons
20	375.02	4.420E-04	-27.76075	-5.088E+20	-6.134E-03	-1.547E+16	14.5379	electrons
21	375	4.420E-04	-26.44846	-5.339E+20	-5.846E-03	-1.623E+16	14.54091	electrons
22	374.98	4.421E-04	-26.14084	-5.401E+20	-5.778E-03	-1.642E+16	14.5427	electrons
23	374.98	4.421E-04	-26.66226	-5.295E+20	-5.894E-03	-1.610E+16	14.54418	electrons
24	375.02	4.420E-04	-24.85666	-5.681E+20	-5.494E-03	-1.727E+16	14.5407	electrons
25	400	4.493E-04	-25.55642	-5.436E+20	-5.742E-03	-1.653E+16	14.78052	electrons
26	400	4.493E-04	-27.49694	-5.053E+20	-6.177E-03	-1.536E+16	14.77926	electrons
27	400.02	4.491E-04	-23.72803	-5.858E+20	-5.328E-03	-1.781E+16	14.77166	electrons
28	400.02	4.492E-04	-25.61597	-5.425E+20	-5.753E-03	-1.649E+16	14.77612	electrons
29	400.04	4.492E-04	-30.82379	-4.509E+20	-6.922E-03	-1.371E+16	14.77511	electrons
30	400	4.490E-04	-27.09117	-5.131E+20	-6.082E-03	-1.560E+16	14.77077	electrons
31	425	4.553E-04	-29.76147	-4.606E+20	-6.776E-03	-1.400E+16	14.97787	electrons
32	424.98	4.550E-04	-25.7451	-5.329E+20	-5.857E-03	-1.620E+16	14.96724	electrons
33	425	4.551E-04	-27.46503	-4.994E+20	-6.250E-03	-1.518E+16	14.97048	electrons
34	424.98	4.547E-04	-25.56999	-5.369E+20	-5.813E-03	-1.632E+16	14.95634	electrons
35	425.02	4.543E-04	-24.77272	-5.547E+20	-5.627E-03	-1.686E+16	14.94393	electrons
36	425.02	4.546E-04	-27.18676	-5.051E+20	-6.179E-03	-1.536E+16	14.95244	electrons

MMR Hall and Van der Pauw Measurement System

JCG3P004 300K-600K 7.5mT 3030G 1mA

Hall Effect Measurement (Statistics)

Fixed Parameters:

Temperature Ramp (K/min)	30
Field (G)	3030
Field Ramp Const.	500
Sensitivity (V/kG)	.00942
Thickness (microns)	.304
K20 Time Constant	100
Current (A)	.001
Number Of Data Points	75

Advanced Parameters:

Number of repetitions	6
Soak Time (min.)	10
Reading Delay (sec.)	3
Temperature setting accuracy (K)	4
Field setting accuracy (%)	1

Points # 1 - 6 (6) Variable Temperature (K) 300.0067 # 1

Parameter	Average	Maximum	+ %	Minimum	- %	St. Dev.
Temperature (K)	300.0033	300.02	5.554E-03	299.98	7.772E-03	1.374E-02
Resistivity (Ohm*cm)	4.238E-04	4.239E-04	3.295E-02	4.237E-04	2.088E-02	7.371E-08
Mobility (cm2/Vs)	-26.55639	-25.40083	4.351336	-28.22956	6.300442	1.063089
Density (cm-3)	-5.555E+20	-5.217E+20	6.08422	-5.800E+20	4.406509	2.185E+19
Hall Coeff. (cm3/Coul)	-5.627E-03	-5.381E-03	4.371401	-5.982E-03	6.310658	2.254E-04
Sheet Number (cm-2)	-1.689E+16	-1.586E+16	6.084221	-1.763E+16	4.406507	6.644E+14
Sheet Res. (Ohm/cm2)	13.94048	13.94507	3.295E-02	13.93756	2.088E-02	2.425E-03
Type of Carriers	electrons					

Points # 7 - 12 (6) Variable Temperature (K) 325 # 2

Parameter	Average	Maximum	+ %	Minimum	- %	St. Dev.
Temperature (K)	324.9967	325	1.024E-03	324.98	5.127E-03	7.449E-03
Resistivity (Ohm*cm)	4.302E-04	4.304E-04	5.464E-02	4.297E-04	9.743E-02	2.347E-07
Mobility (cm2/Vs)	-26.01189	-24.95021	4.081496	-27.31941	5.026639	.9218525
Density (cm-3)	-5.586E+20	-5.314E+20	4.863766	-5.815E+20	4.100301	1.959E+19
Hall Coeff. (cm3/Coul)	-5.595E-03	-5.368E-03	4.058156	-5.873E-03	4.98182	1.983E-04
Sheet Number (cm-2)	-1.698E+16	-1.615E+16	4.863771	-1.768E+16	4.100294	5.955E+14
Sheet Res. (Ohm/cm2)	14.15004	14.15777	5.464E-02	14.13626	9.744E-02	7.719E-03
Type of Carriers	electrons					

Points # 13 - 18 (6) Variable Temperature (K) 349.9933 # 3

Parameter	Average	Maximum	+ %	Minimum	- %	St. Dev.
Temperature (K)	350.01	350.04	8.571E-03	350	2.860E-03	1.528E-02
Resistivity (Ohm*cm)	4.357E-04	4.360E-04	5.903E-02	4.355E-04	4.026E-02	1.384E-07
Mobility (cm2/Vs)	-26.29214	-23.56718	10.36416	-29.78519	13.2855	2.362527
Density (cm-3)	-5.492E+20	-4.810E+20	12.42473	-6.080E+20	10.70263	4.808E+19
Hall Coeff. (cm3/Coul)	-5.728E-03	-5.134E-03	10.37738	-6.489E-03	13.29066	5.146E-04
Sheet Number (cm-2)	-1.670E+16	-1.462E+16	12.42473	-1.848E+16	10.70263	1.462E+15
Sheet Res. (Ohm/cm2)	14.333	14.34146	5.902E-02	14.32723	4.025E-02	4.551E-03
Type of Carriers	electrons					

MMR Hall and Van der Pauw Measurement System

JCG3P004 300K-600K 7.5mT 3030G 1mA

Hall Effect Measurement (Averaged Results)

Fixed Parameters:

Temperature Ramp (K/min)	30
Field (G)	3030
Field Ramp Const.	500
Sensitivity (V/kG)	.00942
Thickness (microns)	.304
K20 Time Constant	100
Current (A)	.001
Number Of Data Points	75

Advanced Parameters:

Number of repetitions	6
Soak Time (min.)	10
Reading Delay (sec.)	3
Temperature setting accuracy (K)	4
Field setting accuracy (%)	1

#	Temperature (K)	Resistivity (Ohm*cm)	Mobility (cm2/Vs)	Density (cm-3)	Hall Coeff. (cm3/Coul)	Sheet N (cm-2)	Sheet R (Ohm/cm2)	Carriers
1	300.0067	4.238E-04	-26.55639	-5.555E+20	-5.627E-03	-1.689E+16	13.94048	electrons
2	325	4.302E-04	-26.01189	-5.586E+20	-5.595E-03	-1.698E+16	14.15004	electrons
3	349.9933	4.357E-04	-26.29214	-5.492E+20	-5.728E-03	-1.670E+16	14.333	electrons
4	375	4.420E-04	-26.61465	-5.314E+20	-5.882E-03	-1.615E+16	14.54063	electrons
5	400.0133	4.492E-04	-26.71872	-5.235E+20	-6.001E-03	-1.592E+16	14.77557	electrons
6	425	4.548E-04	-26.75018	-5.149E+20	-6.084E-03	-1.565E+16	14.96138	electrons
7	449.9967	4.584E-04	-25.71434	-5.306E+20	-5.894E-03	-1.613E+16	15.07937	electrons
8	474.99	4.609E-04	-26.01195	-5.221E+20	-5.995E-03	-1.587E+16	15.16146	electrons
9	499.9967	4.655E-04	-25.18949	-5.349E+20	-5.862E-03	-1.626E+16	15.31153	electrons
10	524.9966	4.676E-04	-24.79105	-5.389E+20	-5.796E-03	-1.638E+16	15.38142	electrons
11	549.9933	4.683E-04	-24.94718	-5.353E+20	-5.842E-03	-1.627E+16	15.4051	electrons
12	575.0067	4.683E-04	-25.34739	-5.269E+20	-5.935E-03	-1.602E+16	15.40537	electrons
13	600.0467	4.679E-04	-23.53358	-5.671E+20	-5.506E-03	-1.724E+16	15.39107	electrons

MMR Hall and Van der Pauw Measurement System

JCG3P004 300K-600K 7.5mT 3030G 1mA

Hall Effect Measurement