Multichip

User Manual

Table of Contents

1. Introduction

Multichip is a program designed to perform and analyze experiments on EFN transistors. Up to 16 transistors may be measured simultaneously. The program includes three different types of experiments, and 13 analysis options.

1. Software requirements

Before using the program, the following software must be installed:

- .NET Framework 3.5 Service Pack 1, or a later version
- Agilent IO Libraries Suite 16.3 Update 2 (later versions might not be able to connect to the SPA)
- Keysight 82350C/82351B GPIB Driver

2. Troubleshooting

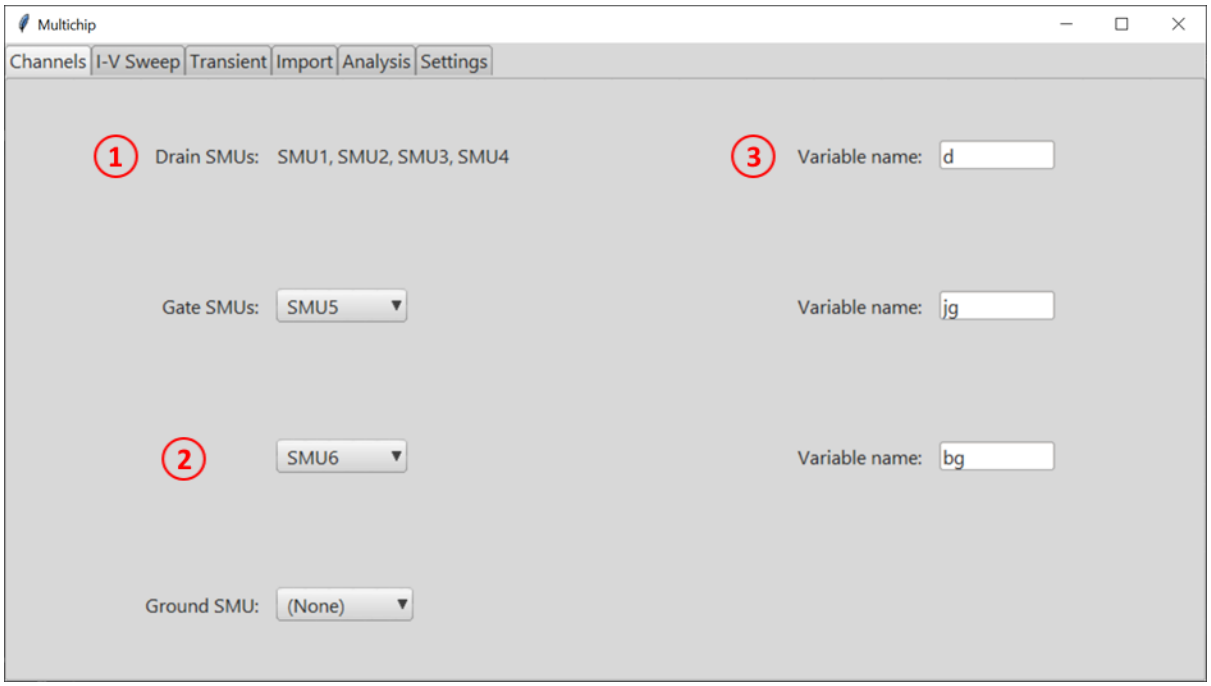
If the program does not start properly, please make sure of the following:

- The SPA is properly connected to the PC via a GPIB cable.
- The SPA is detected in Agilent Connection Expert, and its GPIB address is set to 17. If the GPIB address is different, select the SPA (B1500A), click "Change Properties", and set the GPIB address in the subsequent dialog window.
- The following services are running: Agilent IO Libraries Service, Agilent mDNS Responder Service, Agilent PXI Resource Manager.
- In the SPA's built-in PC, the main interface of EasyExpert is closed, and the "Start EasyExpert" or GPIB I/O windows are displayed.
- The SPA's built-in PC designates the GPIB interface to address no. 17 as well.
- The Arduino is properly connected to the PC via a USB cable.

If the program crashes due to an unexpected error, please find the log file – *logs.log* – in the program folder, and send it to: ofersho2@gmail.com.

The entire code can be found on GitHub here.

2. Channels

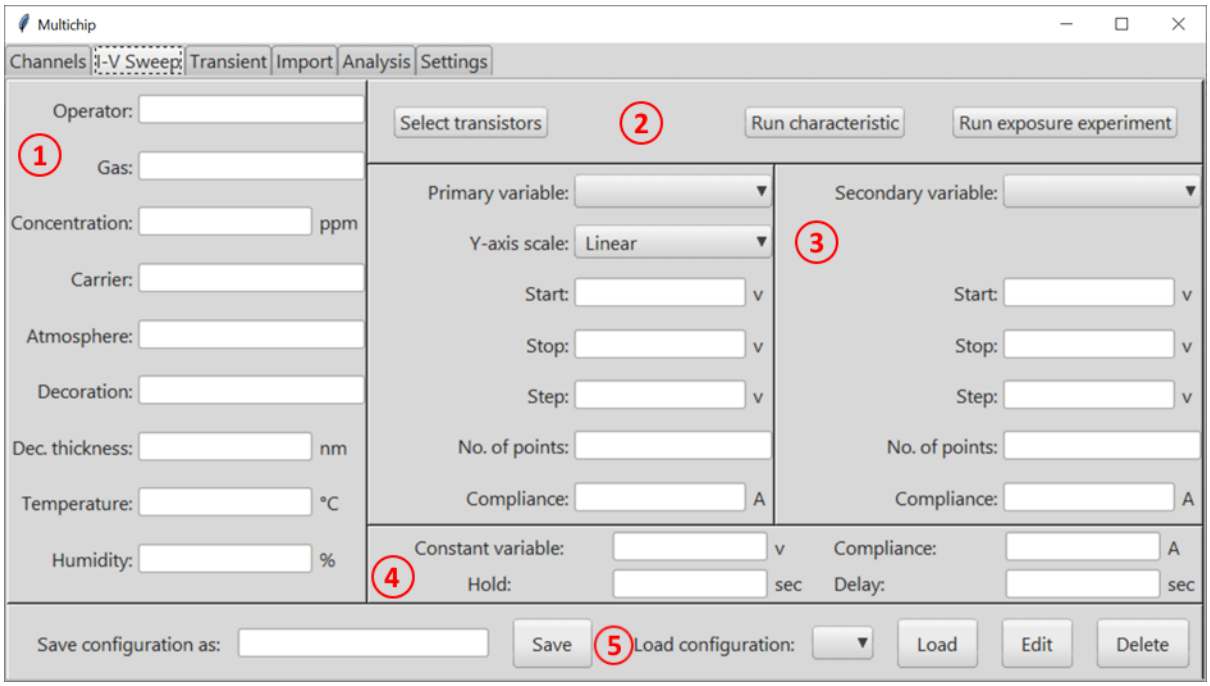


1. Drain SMUs: Displays the SMUs that are allocated to the drains.

2. Gate/Source SMUs: The SMUs that are allocated to the junction gates, back gate, and source can be chosen in the drop-down boxes. These SMUs should be connected to all of the transistors in parallel (via the designated circuit board). The rest of the SMUs are automatically allocated to the drains.
The source SMU may also be set to "(None)", which frees up an SMU to be allocated to the drains or gates. In this case, an external ground must be connected to the sources of the transistors, and the source current will not be displayed.

3. Variable names: The names that correspond to each of the currents (e.g., "d" for the drains, "jg" for the junction gates, and "bg" for the back gates). The voltages and currents will be displayed with these variable names: for instance, "V(d)" and "I(d)". The variable names are initialized with these values, but may be changed manually or by loading a configuration (see sections 3.5, 5.5).

3. I-V Sweep



In this tab, you can set up characteristics and exposure experiments.
A characteristic consists of a set of I-V sweeps, where the voltage axis pertains to the primary voltage, and each sweep is performed at a different value of the secondary voltage.
An exposure experiment consists of two characteristics, and a transient or periodic sweep measurement in between. See sections 4.4 and 5 for more information.

1. Experiment information: The identifying information that will be saved in the experiment files, and shown in the Analysis tab.

2. See sections 6 (Transistor selection), 7 (Experiment window) and 4 (Exposure experiment setup).

3. Sweep parameters:
Primary/Secondary variables: The names of the primary and secondary voltages (as set in section 2.3). Once both are chosen, the constant variable is automatically set.
Y-axis scale: The scale in which the drains' y-axis will be initially displayed in the experiment window. This may be changed in real time during the experiment.
Start/Stop: The lowest/highest voltages of the primary or secondary variable.
Once both are set, the *Step* and *No. of points* fields will be enabled.
Step: The size of the gap between each pair of voltage points.
No. of points: The number of voltage points that will be measured.
Whenever one of these two fields is changed, the other will be set accordingly.
Compliance: The upper limit on the current of each variable, to prevent damage to the devices.

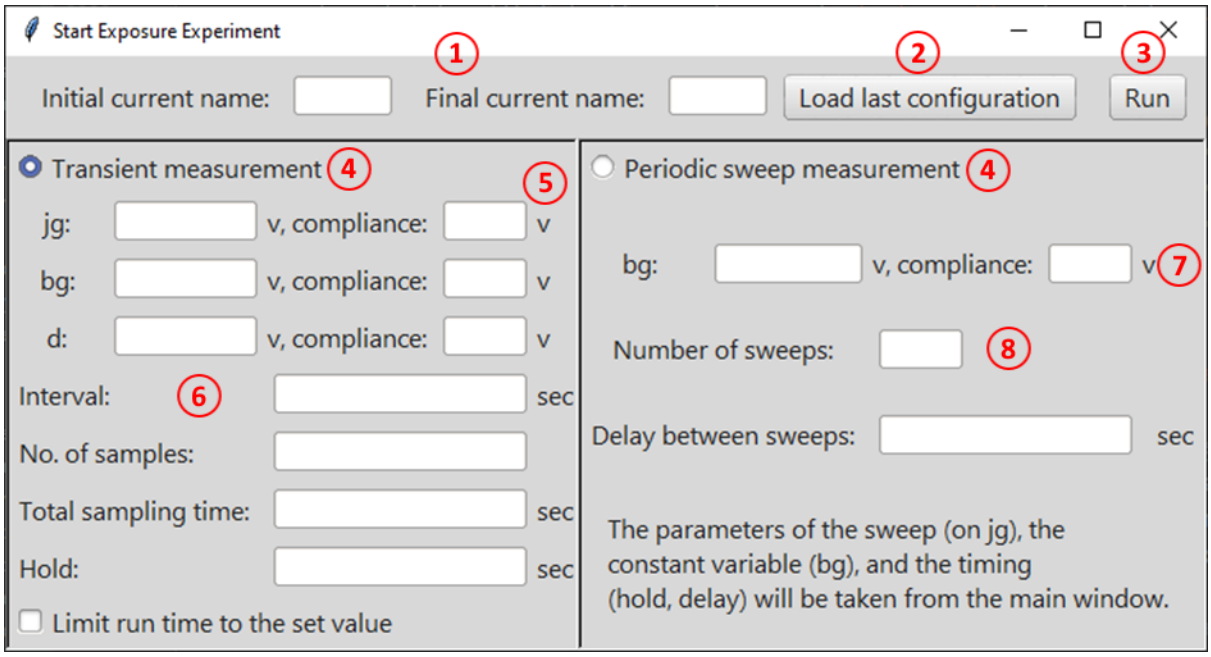
4. Constant variable parameters:
Constant variable: The voltage to which the constant variable will be set throughout the

whole experiment.
Compliance: The upper limit on the current of the constant variable.
Hold: The time delay between each of the sweeps and before the first one, for the purpose of letting the voltage levels stabilize.
Delay: The time delay between each pair of voltage point measurements.

5. Save/Load configurations:

Save: After setting a name, you may save your current configuration. This includes the experiment information and the parameters for all three variables.
Load/Delete: After choosing a configuration from the drop-down list, you may set all the fields to the saved values, or delete the configuration from the list.
Edit: Saves the current parameters to the configuration that is selected in the list.

4. Exposure Experiment Setup



1. Current names: The names that will appear in the results file, corresponding to the pre- and post-exposure currents.

2. Load last configuration: Loads the parameters that were used in the last exposure experiment. They are saved whenever the user starts an exposure experiment, regardless of whether it is completed or aborted.

3. Run: Starts the exposure experiment.

4. Experiment type: Choose the type of the second measurement out of the three – a transient measurement or a periodic sweep.
In a periodic sweep measurement, the secondary voltage is held at a constant value, and an I-V sweep is performed with respect to the primary voltage at set time intervals.

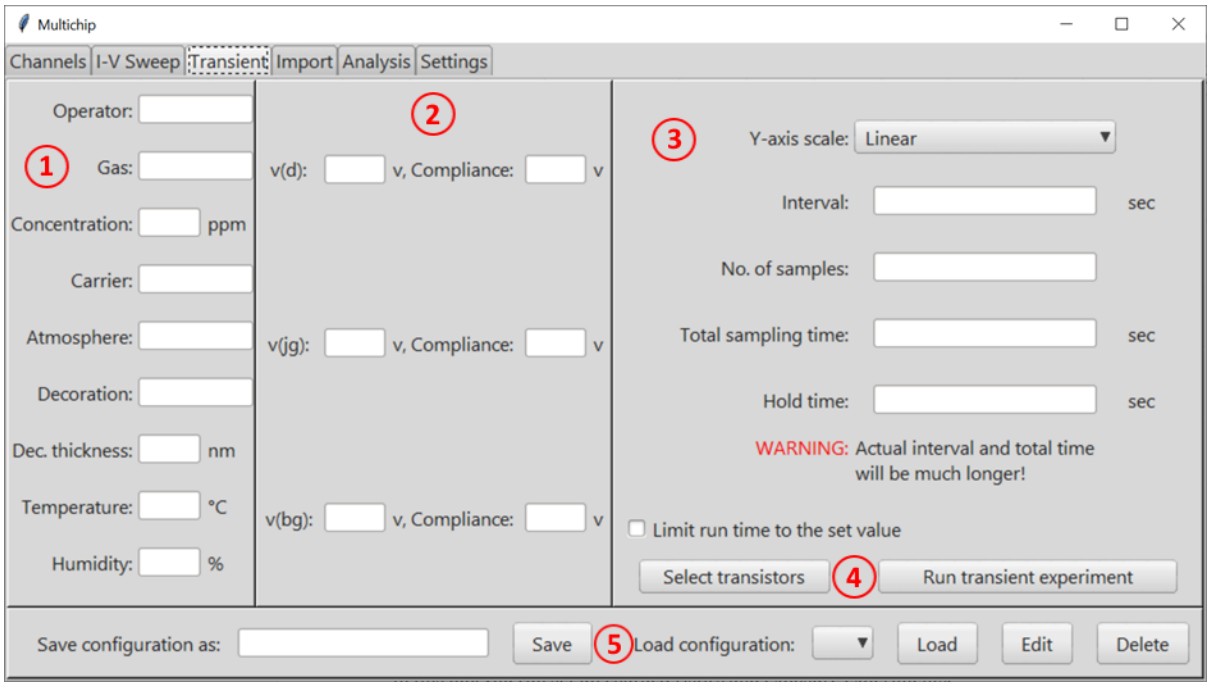
5. Transient measurement – voltage parameters: The voltage and compliance of each of the three variables (which are held constant throughout the measurement).

6. Transient measurement – time parameters: See section 5.3.

7. Periodic sweep – voltage parameters: In a transient sweep, the secondary variable is held at a single constant value – which is set here, along with its compliance.

8. Periodic sweep – time parameters: The number of sweeps that will be performed (for each of the drains), and the delay between each pair of sweeps.

5. Transient



In a transient experiment, all the variables are held at a constant value, and the currents are measured periodically.

1. Experiment information: The identifying information that will be saved in the experiment files, and shown in the Analysis tab.

2. Voltage levels: The voltage and compliance of each of the three variables.

3. Time parameters:
Y-axis scale: The scale in which the drains' y-axis will be initially displayed in the experiment window. This may be changed in real time during the experiment.
Interval: The time delay between each pair of measurements.
No. of samples: The total number of current measurements (per transistor). Disregarded if "Limit run time to set value" is checked.
Total sampling time: The total time of the experiment.
Hold time: The time delay from the moment the voltages are set to the beginning of the measurements.
Limit run time to the set value: The actual interval between measurements may be much longer than the value set by the user, due to the sampling time possibly being non-negligible. As such, if this option is checked, the experiment will end automatically after the total time set by the user has elapsed, even if the actual number of measurements is less than the defined number. Otherwise, the experiment will perform the defined number of measurements, regardless of the total runtime.

4. See sections 6 (Transistor selection), 7 (Experiment window).

5. Save/Load configurations:
Save: After setting a name, you may save your current configuration. This includes the experiment information and the parameters for all three variables.

Load/Delete: After choosing a configuration from the drop-down list, you may set all the fields to the saved values, or delete the configuration from the list.
Edit: Saves the current parameters to the configuration that is selected in the list.

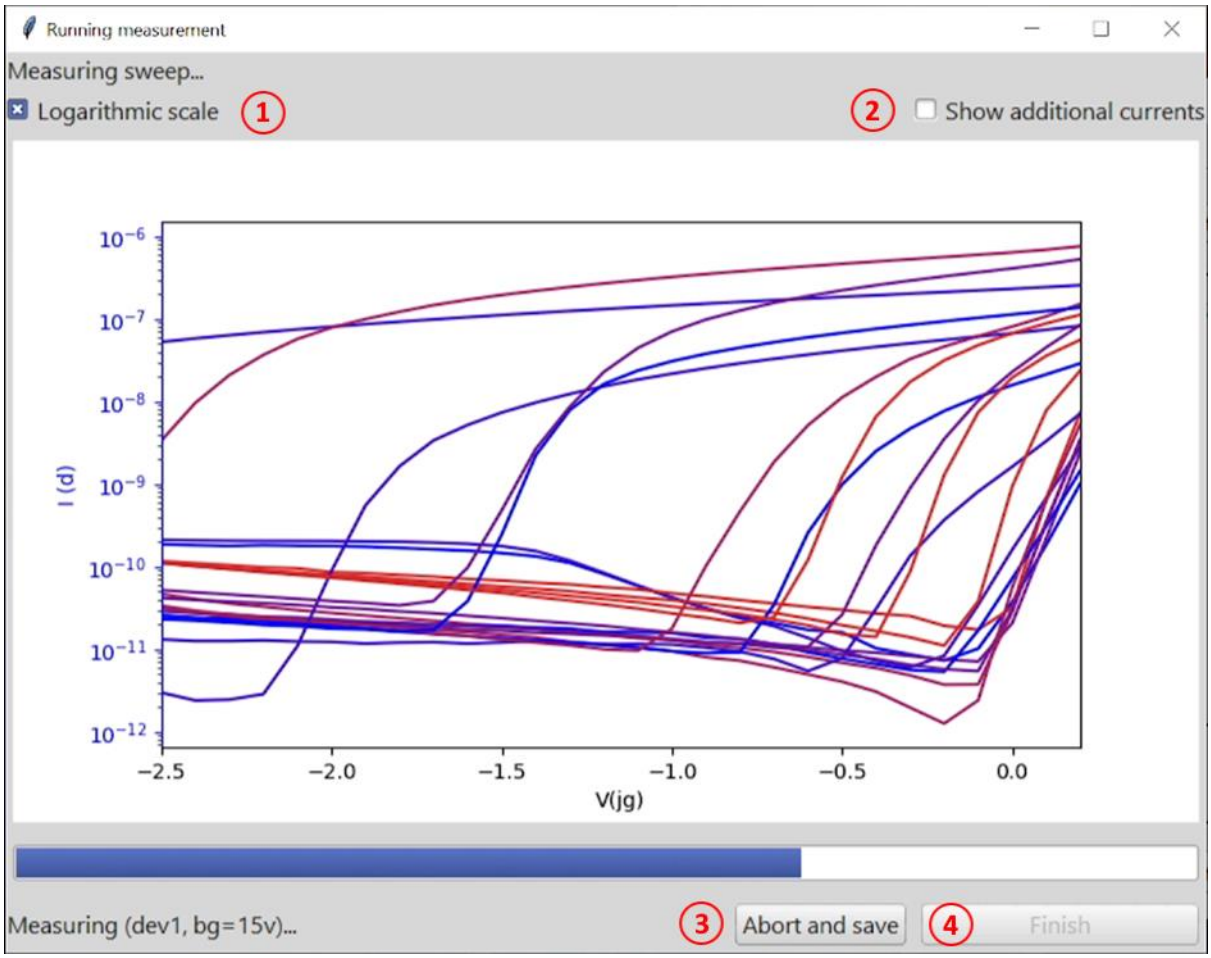
6. Transistor selection

This is the window that will open when the *Select transistors* button is clicked in the *I-V Sweep* or *Transient* tabs.

1. Devices and transistors: Each frame represents a device that includes up to four transistors, and each button represents one of these transistors. Clicking on a transistor button will toggle it between active (green) and inactive (red) modes.
In addition, the user may set the name of each device and transistor, which will then be saved alongside the experiment information.

2. Chambers: Each button corresponds to a different device (which is in a separate chamber). Clicking on one toggles all transistors in its respective device between active and inactive modes. If some of the transistors in the device are active and others are inactive, clicking on the button will disable all of them.

7. Experiment Window



This is the interface that is displayed while running an experiment. Each drain current is displayed in a different color, as set in the *Settings* tab (section 10.2).

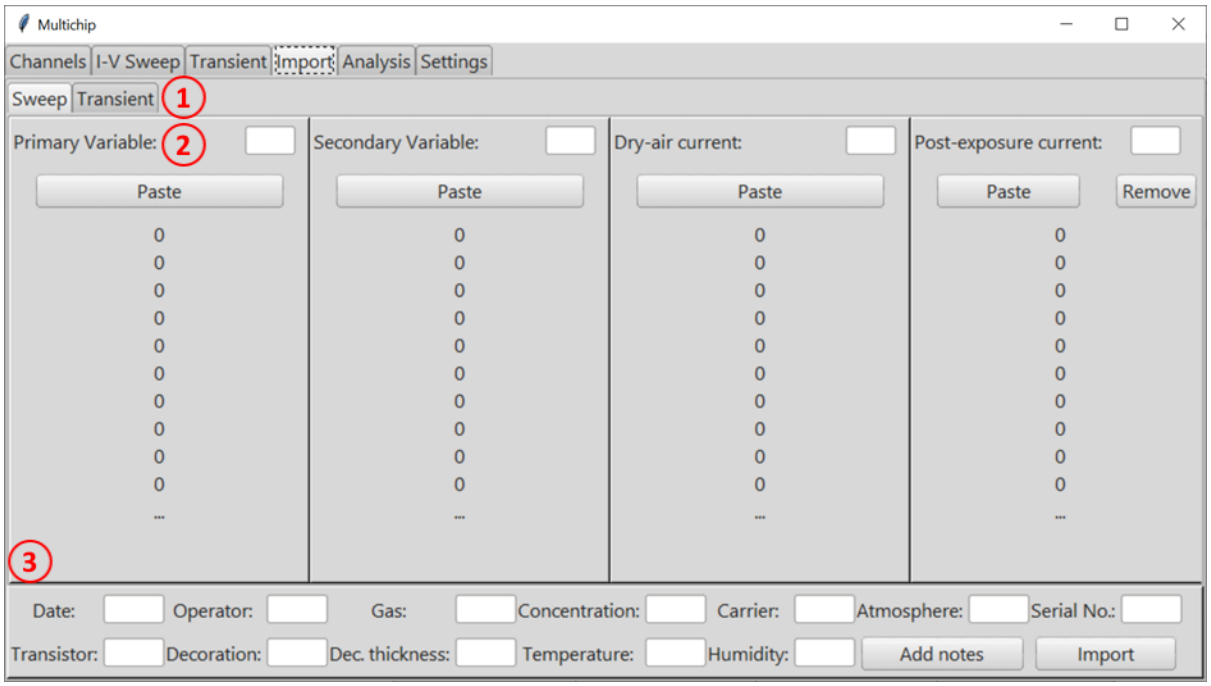
1. Y-axis scale: The scale (linear/logarithmic) of the drains' y-axis. This setting defaults to the option chosen while setting up the experiment. The gate and source currents will always be displayed with a linear axis.

2. Show additional currents: Displays the gate and source currents alongside the drain currents.

3. Abort and save: Saves the measurements that were performed up until this point, and then closes the experiment window.
Note that if the experiment is aborted by pressing the 'X' button instead, the measurements will not be saved.

4. Finish: Saves the measurements and closes the experiment window.

8. Import



In this tab, you may import data from an Excel file into Multichip in order to analyze it. The data must be in the format specified below. For the *Sweep* tab, each variable must be in a separate column, as follows:

- Secondary variable: Each value must repeat itself the same number of times as the number of different values of the primary variable. For example: -1, -1, -1, 0, 0, 0, 1, 1, 1.
- Primary variable: The series of values, as a whole, must repeat itself the same number of times as the number of different values of the secondary variable. For example: 0, 2.5, 5, 0, 2.5, 5, 0, 2.5, 5.
- Currents: Each value corresponds to a different combination of the primary and secondary voltages. In total, the number of values must be the product of the number of different values of the primary and secondary voltages.

For the *Transient* tab (not pictured here), each value in the current columns corresponds to the current measurement at its respective time point. The columns must be the same length.

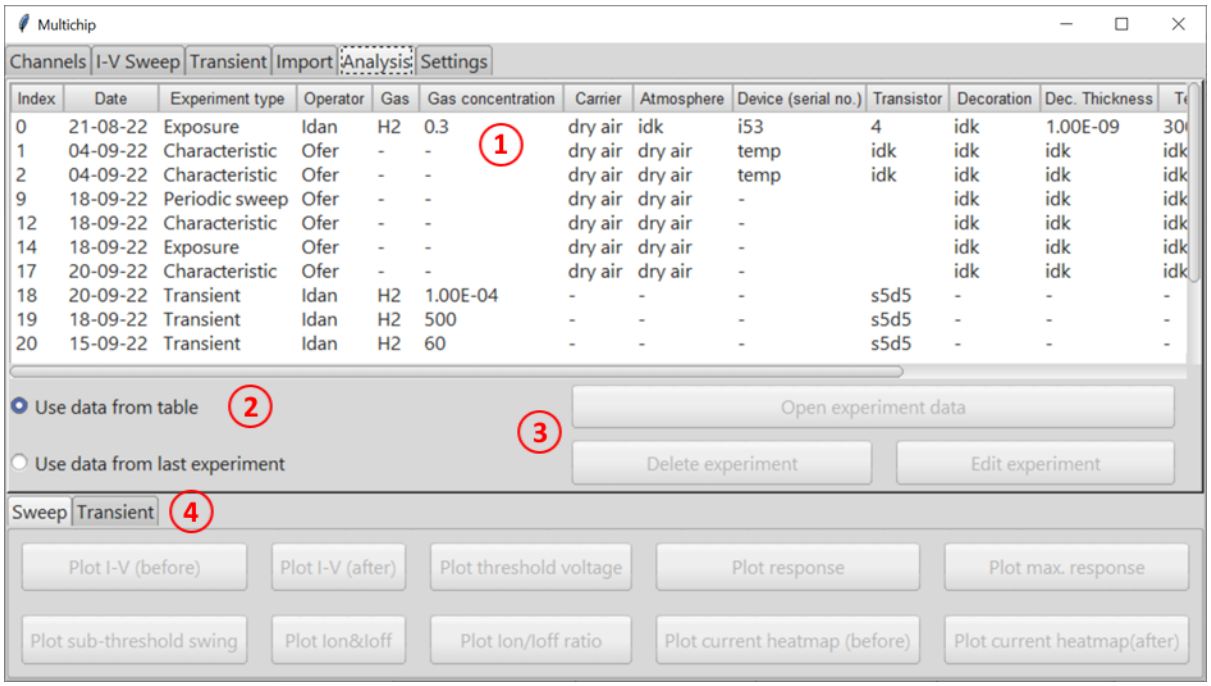
1. Experiment type:
The *Sweep* tab is used to import characteristics and exposure experiments. If a post-exposure current is provided, the data will be saved as an exposure experiment; Otherwise, it will be saved as a characteristic.
The *Transient* tab, which is not shown here, requires the user to input 4-5 columns of data: the time, the drain current, two additional currents (corresponding to the gates) and (optionally) a source current. The data will then be saved as a transient experiment.

2. Data input frames: For each column, you may set the variable name, and then paste its respective data column from the clipboard by clicking the *Paste* button. If the column

that had been copied to the clipboard includes a non-numeric header, it will automatically be set as the variable name.

3. Experiment information: The identifying information that will be saved in the experiment files, and shown in the Analysis tab. To add notes before saving, click the *Add notes* button.

9. Analysis

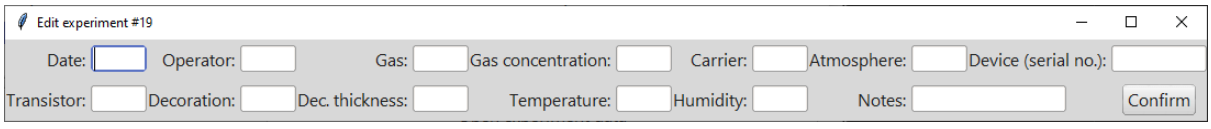


In this tab, you may display the results of past experiments and calculate certain values from the data.

1. Experiment selection: The experiment information, as well as any notes added by the user, is displayed in this table. After selecting an experiment, the appropriate analysis options will be enabled.

2. Data source: If *Use data from table* is selected, the analysis will be performed on the results of the selected experiment. However, if *Use data from last experiment* is selected, the analysis will be performed on the results of the most recently performed experiment. If the experiment was performed on multiple transistors, only the last one's results will be analyzed.

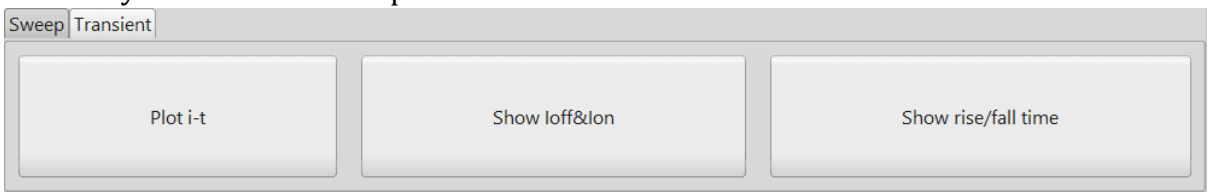
3. Open/Delete/Edit: *Open experiment data* opens the .csv file containing the experiment's data in Excel. *Delete experiment* deletes the experiment's data, both from the table and its .csv file. *Edit experiment* opens the following dialog window, in which the experiment information may be modified:



4. Analysis: The analysis options for characteristic and exposure experiments are as follows:
Plot I-V: Shows the I-V graphs of the drain currents. If the selected experiment is an exposure experiment, you may view the results before or after the exposure.
Plot threshold voltage:
For exposure experiments, plots the threshold voltage for each value of the secondary variable – before and after the exposure, as well as the difference between the two.

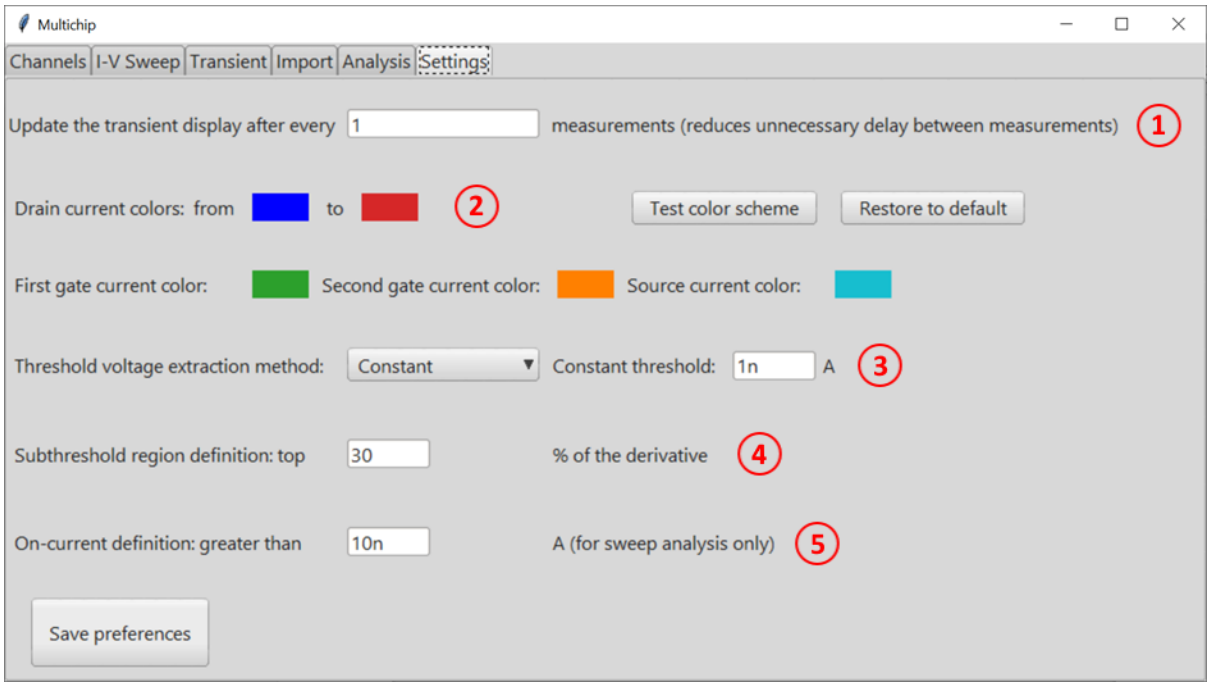
For characteristics, plots the singular threshold voltage for each value of the secondary variable.
Plot response: Shows a heatmap of the response at each primary and secondary voltage. If the pre- and post-exposure currents are denoted as I_i, I_f respectively, the response is defined as: $\frac{|I_i - I_f|}{\min\{|I_i|,|I_f|\}}$.
Plot max. response: Shows the maximum response for each value of the secondary variable.
Plot sub-threshold swing: Shows the sub-threshold swing, which is defined as $S = \frac{\ln(10)}{\left(\frac{dI}{dV}\right)}$ (the derivative is taken in the sub-threshold region), for each value of the secondary variable. For exposure experiments, both functions (before and after the exposure) are plotted on the same graph.
Plot I_{on}&I_{off}、I_{on}/I_{off} ratio: Shows the on- and off-currents, or the ratio between them, on the same graph. For exposure experiments, all four currents (or both ratios) are plotted on the same graph.
Plot current heatmap: Shows the current at each primary and secondary voltage as a heatmap. For exposure experiments, you may view the results before or after the exposure.
Note: For characteristics with only one sweep (that is, the secondary variable only takes one value), the following values are displayed in text form: threshold voltage, sub-threshold swing, on- and off-currents and their ratio. In addition, the current cannot be displayed as a heatmap, so the *Plot current heatmap* buttons display the I-V graph instead.

The analysis for transient experiments are as follows:



Plot I-t: Shows the drain current as a function of the time elapsed.
Show I_{off}&I_{on}: Displays the on- and off- currents (if the current rose by a significant enough amount), in text form.
Show rise/fall time: Detects whether the current rose or fell over the course of the measurement, and displays the rise or fall time respectively in text form.

10. Settings



In this tab, you may set various parameters regarding the experiments and analysis.

1. Transient display update rate: The real-time plotting may take a non-negligible amount of time between measurements. If this is the case, you may set it to update once per several measurements instead. (Note that, besides eliminating the brief delay caused by the plotting, this option does not affect the actual measurement frequency).

2. Color selection: Click each of the boxes to select its respective color. The drains will be colored in a gradient between its two selected colors.
Test color scheme: Displays a plot with example data, to help compare and contrast the colors.
Restore to default: Restores the colors to the ones that are shown in this image.

3. Threshold voltage extraction method:
Constant: The threshold voltage is defined as the voltage at which the current reaches a certain constant value, which can be set by the user.
Linear extrapolation: The I-V graph is fit to a 2-piecewise linear function. Then, the threshold voltage is defined as the right function's intersection point with the x-axis.

4. Subthreshold region definition: Since a typical I-V graph would be split into three segments - constant, exponential, and linear - its log would be split into constant, linear, and logarithmic segments. Of these, the linear segment (exponential in the original graph) would have the highest derivative.
Thus, the subthreshold region is defined as the region where the derivative is at its highest values – for example, the top 30%. This threshold can be adjusted by the user.

5. On-current definition: For the analysis options *Show* I_{on} & I_{off} and *Show* I_{on}/I_{off} *ratio*. The on-current is defined as the average of all the current measurements that are above a certain value, which can be adjusted by the user.