Hall Measurements with MeasureLINK™-MCS Software

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I. Introduction

A basic Hall measurement consists of three steps:

1. Checking the sample contacts to ensure they are ohmic (i.e., linear).
2. Measuring the resistivity. These first two steps are performed at 0 T field.
3. Placing the sample into a known magnetic field and measuring the Hall voltage.

After the completion of these measurements, the derived parameters can be calculated. The FastHall™ station automates the process of entering the required input parameters, collecting the measurement data, and reporting the output results. The steps for completing a standard measurement are shown below.

II. Static Hall Measurement

Sequences for fixed-point Hall measurements are included in the MeasureLINK-MCS™ software. This script completes a Hall measurement at a single field for a van der Pauw or Hall bar sample. To use this sequence, open the software and follow the steps below.

1. Click **Sequence**.
2. In the Sequence ribbon, click **Measurements**.
3. Click **M91 FastHall**.
4. Click **FastHall Measurement**.
5. Fill out the fields in each section of the screen.
6. After setting the parameters, click **Start**. The software will control the magnetic field. For the FastHall station, the software will pause and ask you to move the magnet. When complete, the carrier type should be n and the mobility about 24000 cm^2/(V s).
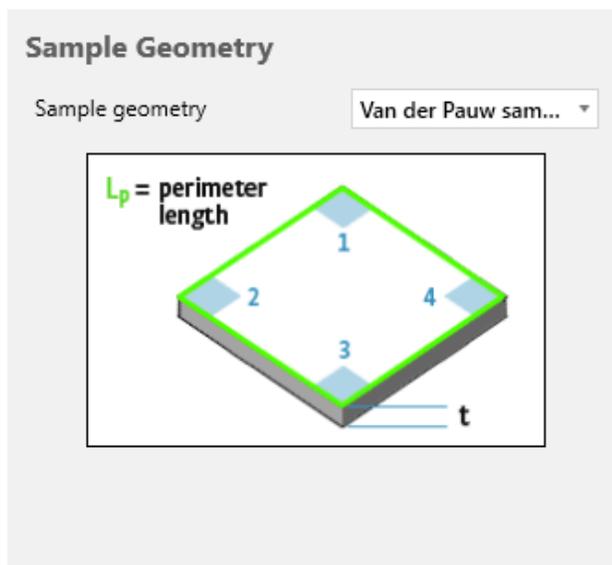
Sample Geometry

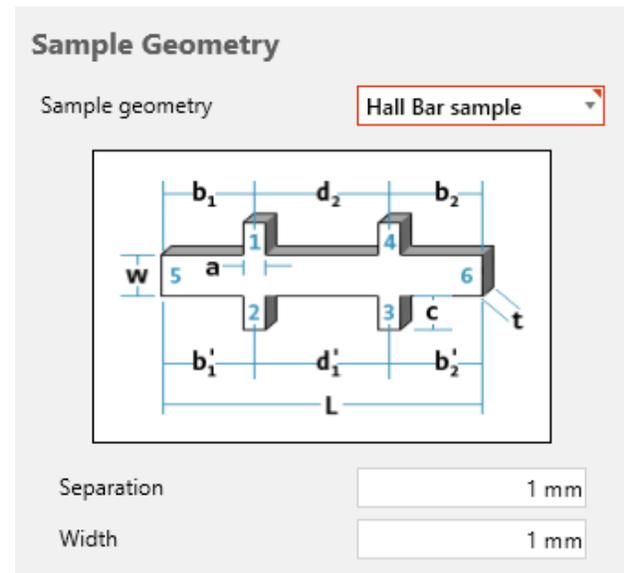Figure 1: **Sample Geometry (van der Pauw sample)**

Figure 2: **Sample Geometry (Hall bar sample)**

Sample Geometry selects the sample type, either van der Pauw or Hall bar. If the sample type is Hall bar, enter the width of the sample and the separation between the arms.
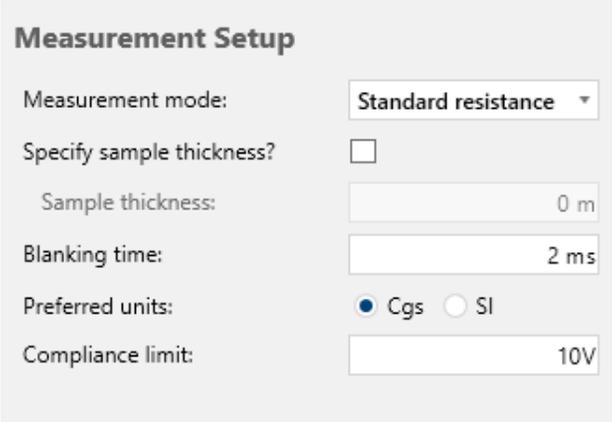
Measurement Setup

*Figure 3: **Measurement Setup***

Measurement Setup defines the sample parameters of the measurement:
- *Measurement mode:*
  - *Standard resistance:* sources the current and measure voltage, and is supported by every M91.
  - *High resistance:* has the capability to source voltage and measure current, which is generally better for high resistance samples.
    NOTE: High resistance mode is only available if the M91 has the high resistance option installed.
- *Sample thickness:* specifies the sample thickness.
  - If the checkbox is not checked, the sample thickness is not specified. The measurement will report sheet values for resistivity, carrier concentration and Hall coefficient.
    Value: enter the thickness in the Sample thickness field. The units of thickness is meters, but the input has several possible formats.
    For example, if the sample thickness is 100 nanometers, the value can be entered several ways:
    a. 100e-9
    b. 1e-7
    c. 100n
       1. In this case the lowercase n is a multiplier (n for nanometers), and the text box will show 100 nanometers.
       2. Allowable multipliers are shown in the following table (case sensitive):

Multiplier	Description	Value
t	tera	10^{12}
g	giga	10^{9}
M	mega	10^{6}
k	kilo	10^{3}
m	mill	10^{-3}
u	micro	10^{-6}
n	tera	10^{-9}
p	pico	10^{-12}
a	atto	10^{-15}

*Table 1: **Allowable multipliers***

- *Blanking time:* the blanking time, in seconds. This value will be overwritten if optimization is used.

- *Preferred units:* selects the units for display results. This choice affects resistivity, mobility, carrier concentration, and Hall coefficient.
  - *SI:* for example, $m^2/(V\,s)$ for mobility.
  - *Cgs:* for example, $cm^2/(V\,s)$ for mobility.
- *Compliance limit:* the compliance voltage or current. Compliance voltage is only available for standard resistance measurements, and compliance current is only available for high resistance measurements.
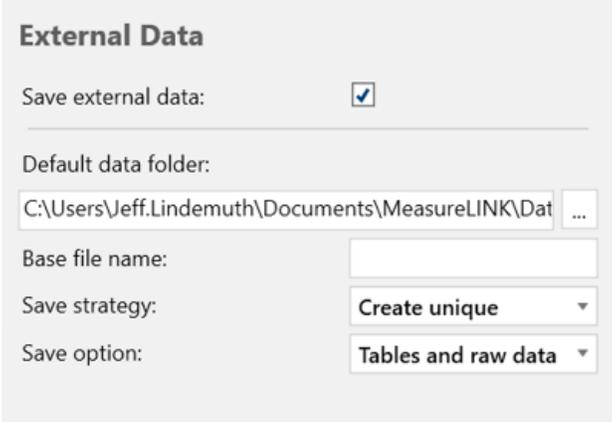
External Data

*Figure 4: **External Data***

External Data defines where and how data will be stored:
- *Save external data:* when checked, data from the measurement will be saved in the user specified directory. If the box is not checked, the data will only be saved in the sequence file.
- *Default data folder:* specifies the base directory to store all data for the measurement.
- *Base file name:* the Base file name from which all file names for this measurement will be generated.
- *Save strategy:* determines how the files are saved:
  - *Create unique:* when this option is selected, a new directory (as a sub directory in the default data directory) is created for each execution of the measurement. The file name is "Run #", where # is an integer, to make the directory name unique.
  - *Overwrite existing:* when this is selected, no unique directories of filenames are generated.
- *Save option:* there are three choices for saving data:
  - *Tables and raw data:* saves any table created by the measurement. Tables will have the extension ".csv" and are stored as comma delimited data files. The raw data will have extension ".html." This is the complete record of all data for the measurement. It is a structured JSON data file.
  - *Only tables:* only the .csv table file will be saved.
  - *Only raw data:* only the raw data will be saved.

  NOTE: In addition to the table and raw data files, there is a summary file with the extension ".html." This file is always saved, except when the choice to save nothing is selected.
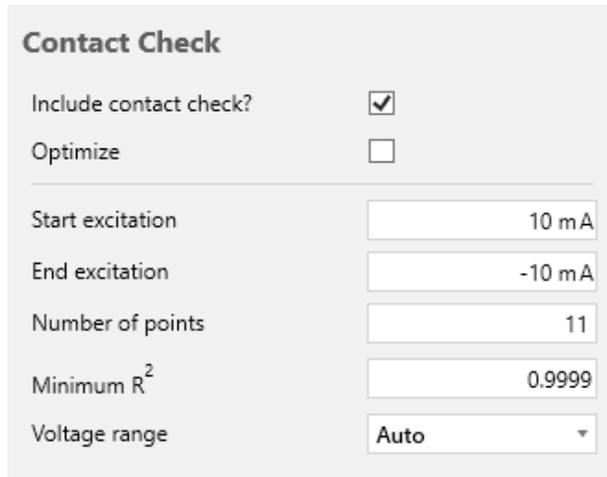
Optimization

*Figure 5: **Optimization***

Use Optimization mode to determine excitation type and values, and blanking time. Click the Optimize checkbox to select the optimization measurement. Include contact check?, if selected, will deselect.

- *Current:* sets the maximum current to apply to the sample. This is a scaled amp input. See Sample thickness in the Measurement Setup section for descriptions of scaled input boxes.
- *Voltage:* sets the maximum voltage to apply to the sample. This is a scaled volt input. See Sample thickness in the Measurement Setup section for descriptions of scaled input boxes.
- *Number of points:* the number of points in the contact check curve.
- *Minimum R^2:* minimum acceptable correlation coefficient.

When the Optimization method is used, the excitation type, excitation value and blanking time are automatically selected for the measurement.

NOTE: When Hall Bar sample is selected as the sample type in Measurement Setup, Optimization is disabled. The current firmware does not support optimization for Hall bars.

Contact Check

*Figure 6: **Contact Check***

When selected, the measurement will complete a contact check.

For standard resistance measurements:
- *Start excitation:* sets the initial current used for the contact check. This is a scaled amp input. See Sample thickness in the Measurement Setup section for descriptions of scaled input boxes.
- *End excitation:* sets the final current used for the contact check. This is a scaled amp input. See Sample thickness in the Measurement Setup section for descriptions of scaled input boxes.
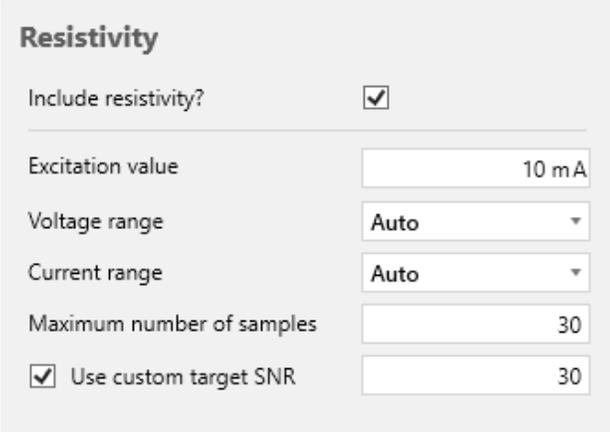
For high resistance measurements:
- *Start excitation:* sets the initial voltage used for the contact check. This is a scaled volt input. See Sample thickness in the Measurement Setup section for descriptions of scaled input boxes.
- *End excitation:* sets the final voltage used for the contact check. This is a scaled volt input. See Sample thickness in the Measurement Setup section for descriptions of scaled input boxes.

For all measurements:
- *Number of points:* the number of points in the contact check curve.
- *Minimum R^2:* minimum acceptable correlation coefficient.
- *Auto range:* when selected, the measurement range will be determined automatically. If Auto range is not selected, the user must select the measurement range. If the excitation type is current, the range to be selected is the voltage measurement range. If the excitation type is voltage, the range to be selected is the current measurement.

Resistivity

*Figure 7: **Resistivity***

When selected, the measurement will complete a resistivity measurement.

For standard resistance measurements:
- *Excitation value:* sets the current used for the resistivity measurement. This is a scaled amp input. See Sample thickness in the [Measurement Setup section](#) for descriptions of scaled input boxes.

For high resistance measurements:
- *Excitation value:* sets the voltage used for the resistivity measurement. This is a scaled volt input. See Sample thickness in the [Measurement Setup section](#) for descriptions of scaled input boxes.
- *Auto range:* when selected, the measurement range will be determined automatically. If Auto range is not selected, the user must specify the measurement range for both current and voltage.
- *Maximum number of samples:* the number of samples to use. For a value of SNR ratio, the maximum number of samples in the measurement. The measurement will stop when the target SNR is reached, or the number of samples reaches the maximum number of samples.
- *Use custom target SNR:* when checked, the M91 calculates the signal to noise ratio (SNR) for each measurement after the 10th. If the SNR is greater than the custom target SNR, the measurement will stop. If the maximum number of samples is reached before the target SNR is reached, the measurement will terminate. Enter an SNR value.

Hall Measurement

*Figure 8: **Hall***

When selected, the measurement will include a Hall measurement.

- *Sample mode:* select a method:
  - *Fast Hall:* uses the FastHall™ method.
  - *DC Hall:* uses the DC Hall measurement. This will use field reversal.
  - *DC Hall No Reversal:* uses DC Hall measurement without field reversal.

NOTE: When Hall Bar sample is selected as the sample type in Measurement Setup, only the DC Hall and DC Hall no field reversal methods are available.

For standard resistance measurements:
- *Excitation value:* sets the current used for the Hall measurement. This is a scaled amp input. See Sample thickness in the Measurement Setup section for descriptions of scaled input boxes.

For high resistance measurements:
- *Excitation value:* sets the voltage used for the Hall measurement. This is a scaled volt input. See Sample thickness in the Measurement Setup section for descriptions of scaled input boxes.
- *Enable field control?:* check this checkbox to enable field control.
- *Magnetic field:* the value of the magnetic field to use in the measurement. Can be positive, negative or zero. Field value is Tesla (T).
- *Additional field wait time:* Sets an additional wait time, in seconds, after the field controller is settled. The default value is 0.
- *Auto range:* when selected, the measurement range will be determined automatically. If Auto range is not selected, the user must specify the measurement range for both current and voltage.
- *Maximum number of samples:* the number of samples to use. For a value of SNR ratio, the maximum number of samples in the measurement. The measurement will stop when the target SNR is reached, or the number of samples reaches the maximum number of samples.
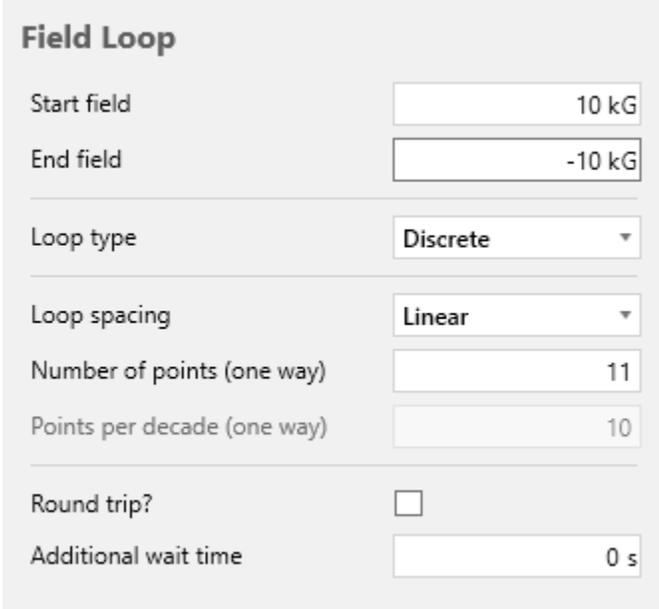
- *Use custom target SNR:* when checked, the M91 calculates the signal to noise ratio (SNR) for each measurement after the 10th. If the SNR is greater than the custom target SNR, the measurement will stop. If the maximum number of samples is reached before the target SNR is reached, the measurement will terminate. Enter an SNR value.

III. Variable Field Hall Measurement

To complete a variable field Hall measurement, open the MeasureLINK-MCS™ software and follow these steps:

1. Click **Sequence**.
2. In the Sequence ribbon, click **Measurement**.
3. Click **M91 FastHall**.
4. Click **Variable Field FastHall measurement**.
5. Fill out the fields in each section of the screen, as shown on the following pages.
6. After setting the parameters, click **Start**. The software will tell you when to move the magnet.

Field Loop, Discrete

*Figure 9: **Field Loop (Discrete)***

When selected, the measurement will include field loop data:

- *Start field*: starting field value for the field swept Hall measurements.
- *End field*: last field value for the field swept Hall measurements. After measurement execution, the field is returned to 0 T.
- *Loop type:* a Discrete loop stabilizes the field at the preset number of steps and waits for the field to settle at each field before completing the Hall measurement. In addition to the Number of points, the user must also specify the type of Loop spacing.
- *Loop spacing:*
  - *Linear:* equally spaced field points
  - *Log:* logarithmic
- *Number of points (one way):* for linear spacing, the total number of points.
- *Points per decade (one way):* For log spacing, the number of points in each decade of the field step.

- *Round trip?:* directs the software to perform a second field loop with all the settings the same except that the Start field and End field settings are reversed. When this is selected, an Additional wait time can be entered before the return trip begins.
- *Additional wait time:* Additional wait time after field settles.
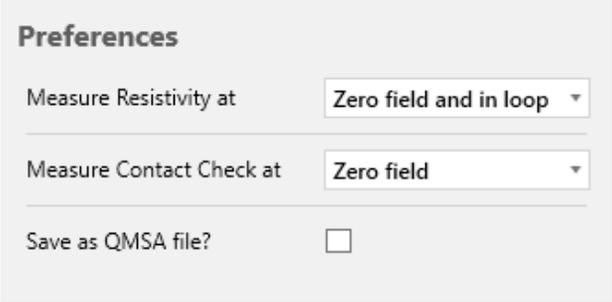
Field Loop, Continuous

*Figure 10: **Field Loop (Continuous)***

When selected, the measurement will include field loop data:
- *Start field*: starting field value for the field swept Hall measurements.
- *End field*: last field value for the field swept Hall measurements. After measurement execution, the field is returned to 0 T.
- *Loop type:* a continuous loop starts at the Start field and waits for the field to stabilize, then the field ramps to the End field at the user-specified field ramp rate. Hall measurements are taken at fixed intervals, specified to be either fixed time intervals or fixed field intervals. In addition, the continuous mode also supports stopping after a given number of Hall measurements are complete, or continuing until the End field.
- *Ramp rate:* specify the field ramp rate in field/min.
- *Ramp field from:* choose either the Start field value of the current field value.
- *Interval type:* choose either Time or Field.
- *Time interval:* time between measurements, in seconds.
- *Field interval:* field increment between measurements.
  Collect data for: either the entire ramp duration or the number of points specified.

- *Round trip?:* directs the software to perform a second field loop with all the settings the same except that the First field and Last field settings are reversed. When this is selected, an Additional wait time can be entered before the return trip begins.
- *Additional wait time:* Additional wait time after field settles.

Preferences

*Figure 11: **Preferences***

Preferences defines where and how data will be stored:
- *Measure Resistivity at/Measure Contact Check at:* these settings control when the Resistivity and Contact Check measurements are completed during the field sweep:
  - *Zero field:* completes a resistivity or contact check measurement at 0 T before the sweep begins. The mobility will always be calculated using the zero field resistivity.
  - *In Loop:* does not do a zero field resistivity/contact check, only measures in the loop.
  - *Zero field and in loop:* measures contact check/resistivity at zero field and at each field value in the loop.
- *Save as QMSA file?:* if checked, an additional text file is created. This text file can be used as input to the Lake Shore Cryotronics QMSA program.
  NOTE: if QMSA data is required, the resistivity must be measured at zero field and in loop.

Results Options

*Figure 12: **Results Options***

Results Options allows selection of plots and data displayed during the measurement:
- *Field Loop Results Charts:* select from the list results.
- *For each loop measurement:* select what results are displayed for each field point in the loop.

Optimizing Measurement Time with Variable Field Hall Measurements and QMSA Data

Hall measurements using the FastHall™ method do not require field reversal. However, field reversal should be used with the DC Hall method. This section describes a method to reduce the measurement time of variable field Hall measurements when using DC field Hall methods.

QMSA data has several rules, which the script enforces. These include:
- Values are always sheet values, even if a thickness is entered.
- Resistivity must be measured at zero field and within the field loop.
- If cgs units are selected, the field is in Oersted not Tesla.
- A maximum of 30 field points. If more than 30 points are measured, the script randomly picks the excess points to remove from the QMSA file. All data is stored in the .csv files for the measurement.
- The Hall coefficient carries the sign of the carrier type: negative for n-type, positive for p-type.

The file name of the QMSA data file is "Base File Name QMSA data.txt" and is stored in the root data directory of the measurement. This .csv file for the field loop is located in the same directory.

Variable Field Hall Measurements Using the DC Hall Method

Assuming the QMSA data is required, the resistivity must also be measured at field. For example, with a simple three-field variable field Hall measurement, label the fields f_1, f_2, and f_3. If the DC Hall method with field reversal is used in the M91 measurement controller, the following sequence is used:

1. Go to field f_1.
2. Measure resistivity at field.
3. Start DC Hall:
   a. Measure positive field.
   b. Go to $-f_1$.
   c. Measure negative field.
   d. Return field reversed data.
4. This sequence is repeated for fields f_2 and f_3.

   NOTE: In this method, there are three excursions (one for each field) from positive field to negative field.

The variable field Hall measurement adds one additional sample mode to the Hall panel. This is DC Hall optimized. The following is an explanation of this mode.

In this example, assume f_1 is the Start field and is greater the f_3, the End field:

1. Field is swept to f_1.
2. Resistivity is measured.
3. DC Hall no field reversal is measured.
   Results: These results are stored in measurement result (and table) positive field results.
4. Repeat steps 1 through 3 for fields f_2 and f_3, completing the positive field results.
5. Field is swept to $-f_3$.
6. Resistivity is measured.
7. DC Hall no field reversal is measured.
   Results:
   - These results are stored in measurement result (and table) negative field results.
   - The results at $-f_3$ are matched with the results at f_3 and the field reversed results are calculated. These are stored in measurement results (and table) field reversed results.
   NOTE: The field reversed calculations are done in the script not in the M91.
8. Repeat steps 5 through 7 for fields $-f_2$ and $-f_1$.
9. QMSA data is generated from the field reversed measurement.
   NOTE: This method is like the method used in the Lake Shore Model 7700 and the 8400 Series HMS, and the field is swept only once from f_1 to $-f_1$.

IV. Variable Temperature Hall Measurement

Variable temperature can be done by using MeasureLINK temperature loops, either Continuous or Discrete. Both the M91 Hall Measurement and the M91 Variable Field Measurement can be inserted into the temperature loops.

V. Service

The Lake Shore Technical Support Department is staffed Monday through Friday between the hours of 8:00 a.m. and 5:00 p.m. EST, excluding holidays and company shut down days.

Contact Lake Shore Technical Support through any of the means listed below. However, the most direct and efficient means of contacting is to complete the online service request form at http://www.lakeshore.com/support/. Provide a detailed description of the problem and the required contact information. You will receive a response within 24 hours or the next business day in the event of weekends or holidays.

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	614-818-1609	Instrument Service
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