Rev. 1 Jan. 2024 – Xiangkai Liu

Lakeshore M81-SSM Measurement SOP

Take Hall-measurement as example

Setup

The Lake Shore M81-SSM Synchronous Source Measure System as shown in Figure 1 is a modular system for applying voltage and current stimulus to the experimental system, as well as measuring voltages and currents produced by the experimental system. On the right column in Figure 1, from top to bottom, each module corresponds to BCS-10 balanced-current source (S1), VS-10 voltage source (S2/Vs, S3/Vs_10), VM-10 voltage measure (M1/Vm, M2/Vm_10), and CM-10 current measure (M3).

Figure 1. Lake Shore M81-SSM system

Communication Connection

To ensure the M81-SSM system is connected to the CRX-VF desktop, first check the USB cable of the M81-SSM system is connected to the USB port of the desktop, as shown in Figure 2.

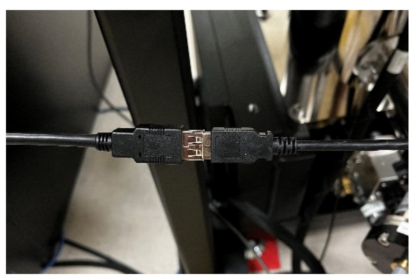


Figure 2. M81-SSM system USB cable connection

On the MeasureLink interface, check that magnetic field controller is turned on (but do not apply any current to the supermagnet at this stage), as is shown in Figure 3, so that the measurement sequence could be created or edited. Also check that M81 Source/Measure System ("M81") is turned on, as is shown in Figure 4, so that the MeasureLink will initiate and establish the control of the M81-SSM system.

- **Please note that magnetic field should NEVER be ramped if the magnet is not cooled down by CCR, and the field controller is turned on only for the purpose to open or edit the sequence file. Failure to comply will result in the serious damage of the magnet.**
- **Also please pay attention that the applied magnet field must follow the temperature limits in Table 1 when charging the superconducting magnet. Failure to comply will result in the serious damage of the magnet.**

Maximum magnetic field capability	Magnet temperature for safe operation	Sample stage temperature
±2.5 T	<5 K	Base
±2 T	<5.5 K	10 K to 400 K

Table 1. Maximum magnetic field capability at sample temperature

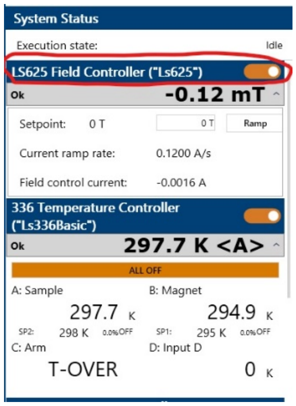


Figure 3. MeasureLink connection interface-1

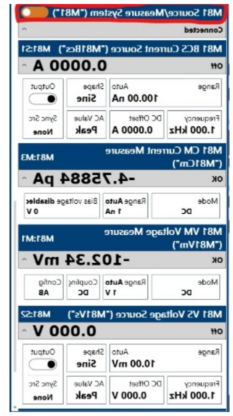


Figure 4. MeasureLink connection interface-2

Sequence Creation

Go back to Home tab in the top left corner of Measurelink and click on Sequence, as is shown in Figure 5. Most useful icons are: Measurements, Loops, Controls, and Data, as is shown in Figure 6.

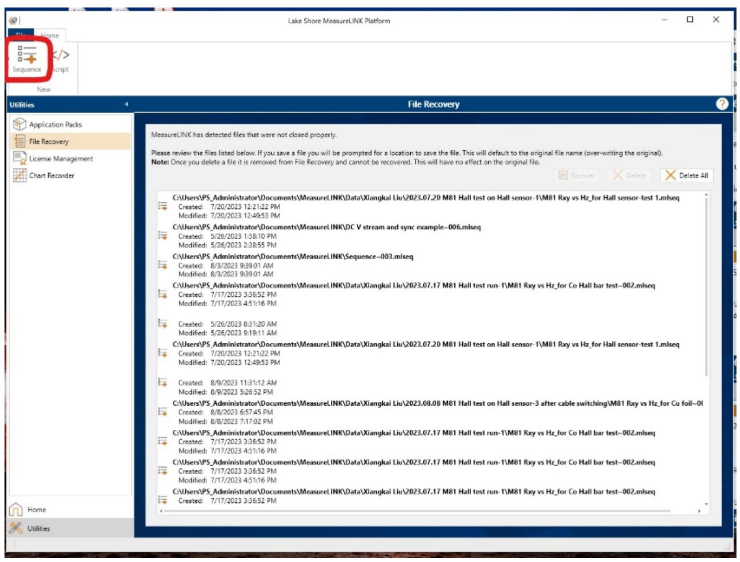


Figure 5. MeasureLink home page for sequence creation

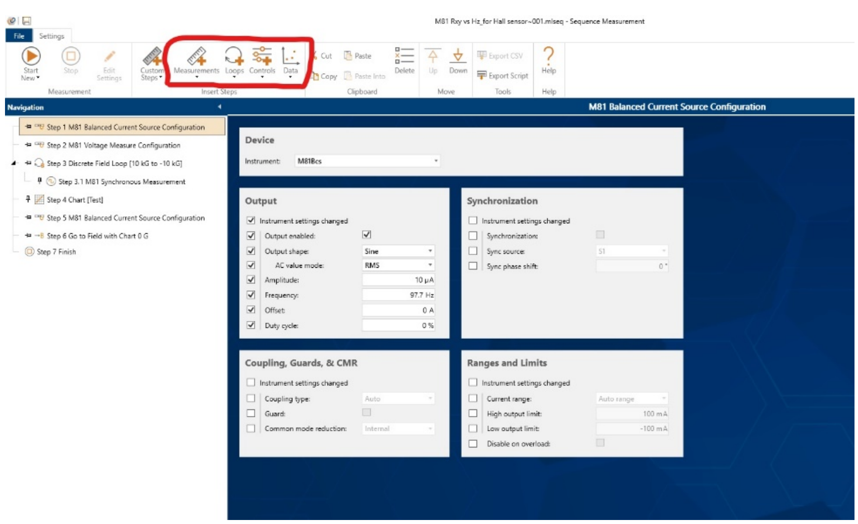


Figure 6. Sequence creation page

Measurements

1. Below are options inside "Measurements" icon.
2. For M81: M81 Source/Measure from drop-down list, select either stream or synchronous measurements. Stream: continuous measurements; synchronous: one-time measurement
3. For Stream/Synchronus measurements:
   Click "Add parameter" to add in the values to measure. Can either measure from a measurement device or source device. (Measuring from source device, for example voltage output of the voltage source, is required if any data from source is to be used in plotting function that is going to be discussed later). For synchronous, choose proper settle time; for stream, choose sampling rate and time/datapoints (row count).

Loops: (for field, temperature, voltage, current)

4. Choose the instrument for the loop.
5. Measurelink allows setting up loop in another loop (nested loop). If needed, create two loops separately and drag the sub-loop into main loop. Similar idea applies to other steps to be included in the loop, dragging is the method.

Control: (setting a constant configuration for PPMS, M81, till next time it gets changed through loop/another control instruction)

6. Control steps should always be set first before the measurements to adjust measurement configuration and source configuration. User needs to individually configure each measurement/source device used in experiment.
7. Control for source: Using M81 VS as an example, as shown in Figure 7, click on instrument settings changed when a change should be applied to the voltage source. Select output enabled to turn on output. Adjust amplitude, frequency and offset if needed.

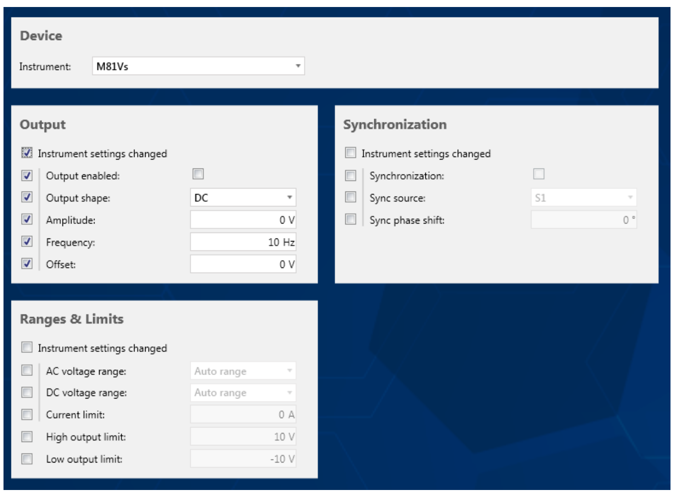


Figure 7. Control for source editing page

8. Control for measurement: Using M81 VM as an example, as shown in Figure 8, click on instrument settings changed when a change should be applied to the voltage source. Available modes are DC, AC and LIA (locked-in amplifier). LIA is an important method to eliminate noise and amplify the signal of interest. Averaging time can be left at 1NPLC (number of power line cycle), but can also be set to other values to reduce noise at 60Hz. Choosing A-B, A or Ground as the input. Tune lock-in settings to X,Y or R theta data collection and refer the measurement to the source with excitation frequency setting. Change reference harmonic values if needed, or just leave it as 1.

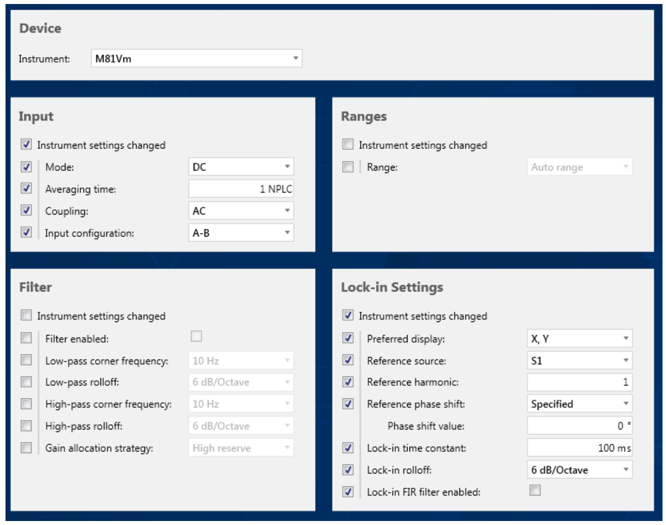


Figure 8. Control for measurement editing page

Data: (embedded plotting function)

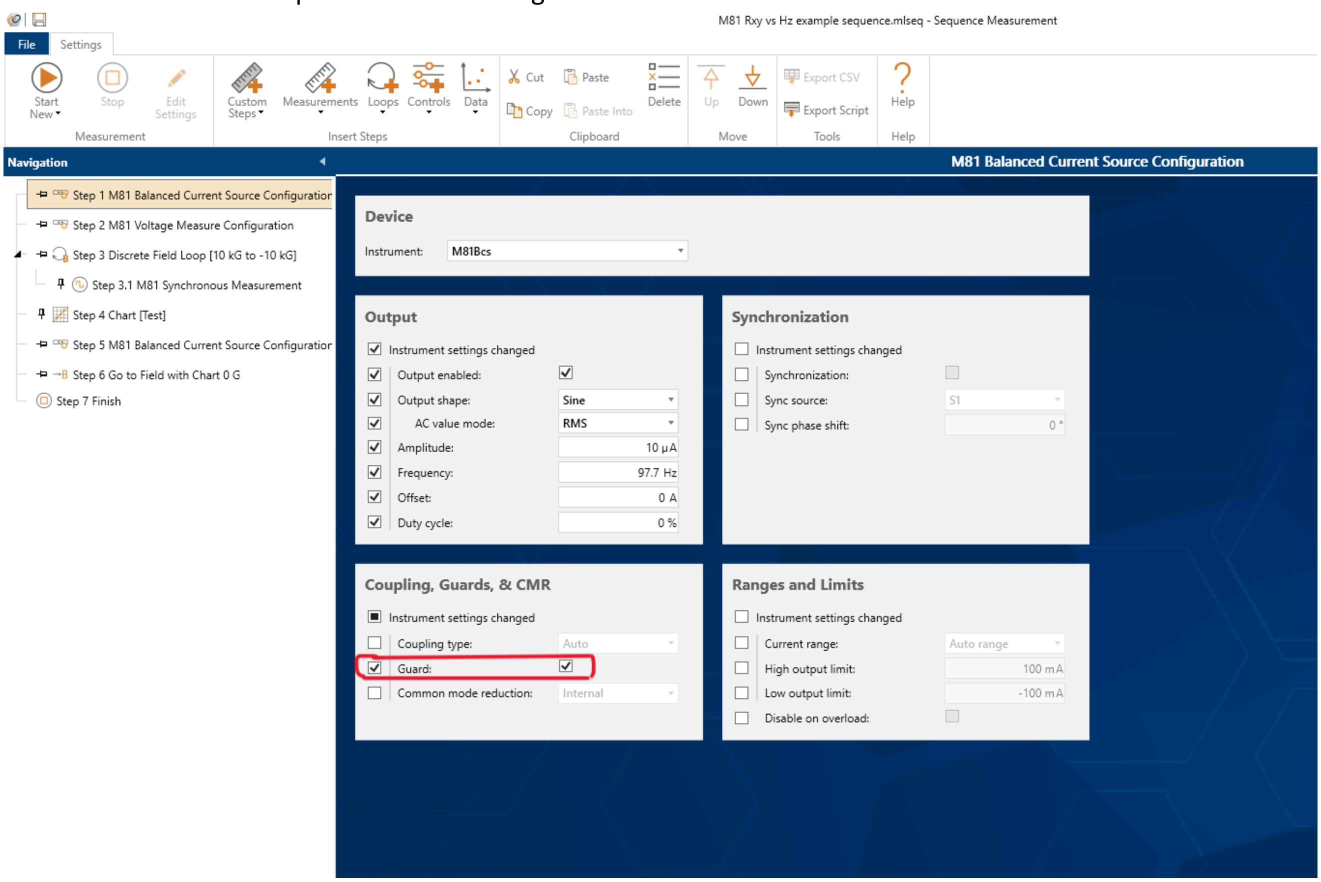
9. Go to series to set up the plotting style and data to be plotted. Click on the series or axes folder icons to add new plots or axes to be plotted. User can choose data to be plotted in series and format the chart. Formatting axis can be done in the corresponding axis row (scale type – linear/log, data type and alignment information).

Finishing Off

10. Save sequence if needed for future use, user can always create and store your own sequence so that next time you can easily duplicate your previous setup and run the experiment quickly.
11. Always, at the end of your sequence, add in control steps to return everything back to normal (turn off sources, reset the field back to default values).
12. When everything is finished, user can choose export options on top bar to save data.

Detailed step for Hall Measurement

1. After starting MeasureLink and creating the communication between M81-SSM system and the desktop, open the example Hall-measurement sequence file at this directory: "C:\Users\PS_Administrator\Desktop\Example programs\M81 Rxy vs Hz example sequence.mlseq". We'll take a look at how this example sequence is created in the following steps.
2. First, BCS-10 balanced current source is used as the current source, we need to configure it. Click on Controls -> M81 Source/Measure -> M81 Balanced Current Source Configuration to create configuration step for BCS-10. It is recommended to **use triaxial cables for the BCS-10 connection** to reduce leakage current.
3. As shown in setup 1, the example uses a Sine wave of 10 uA RMS as the current source with the frequency of 97.7 Hz. Because we are using lock-in amplifier of VM-10 (LIA mode) to measure Hall bar, choose output shape to be Sine and set a prime number frequency that is not close to AC wall wart voltage frequency. Please **enable the Guard function** to minimize the effective capacitance and leakage current.



Setup 1. Current source configuration

4. Then we need to configure the voltage measurement instruments. Click on Controls -> M81 Source/Measure -> M81 Voltage Measure Configuration. As shown in setup 2, select the M81 VM-10 Vm as the voltage measurement device. Set the measurement to LIA mode and coupling to DC mode. Here set the reference source accordingly to S1. Can also verify the source information by clicking on M81 instrument to check which instruments are connected to S1, S2 etc.
5. Next we need to set up the parameters of the lock-in low-pass filters. Two types of filters, i.e., **IIR** and **FIR** need to be set up in this step.
   IIR filters contain two parts, the **lock-in time constant t_c** and **roll-off**. Set t_c according to the source current frequency f, and in principle it should be at least 3 times of 1/f, such that a few rounds of integration would be performed and the DC noise could be well removed. For example, with AC current frequency set at 97.7 Hz, here we choose t_c to be 300 ms.

The lock-in roll off determines how sharp the noise could be cut-off, but also impacts how long it would take for the signal to settle. It is a trade-off between the two factors, as the higher roll off, the longer time taken for the signal to settle, as is demonstrated in Figure 9. Empirically the settle time $\mathbf{t_{settle}}$ is in relation to t_c as $\mathbf{t_{settle} = 10\sim15\ t_c}$. Here we choose 24 dB/octave roll off, so the full settle time t_{settle} would be about 5 s.

On the other hand, the FIR filter could be enabled to further reduce the noise. The cycle numbers **N** could be chosen in the principle of $\mathbf{N*t_c \leq t_{settle}}$. Here we choose **N be 10** for noise reduction.

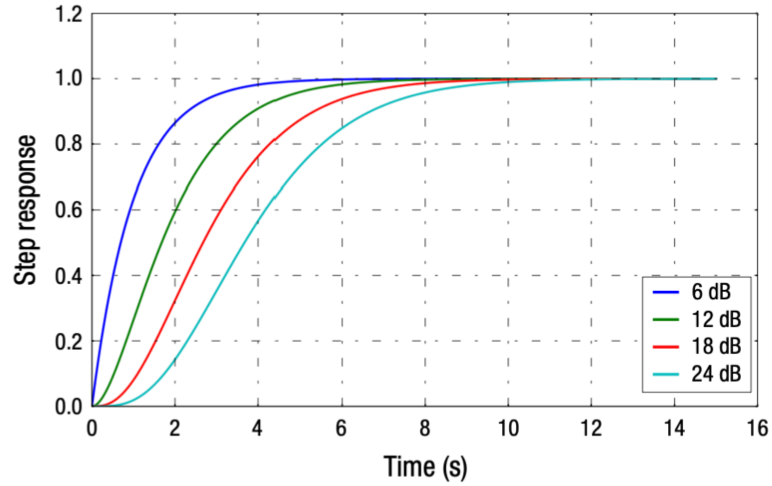
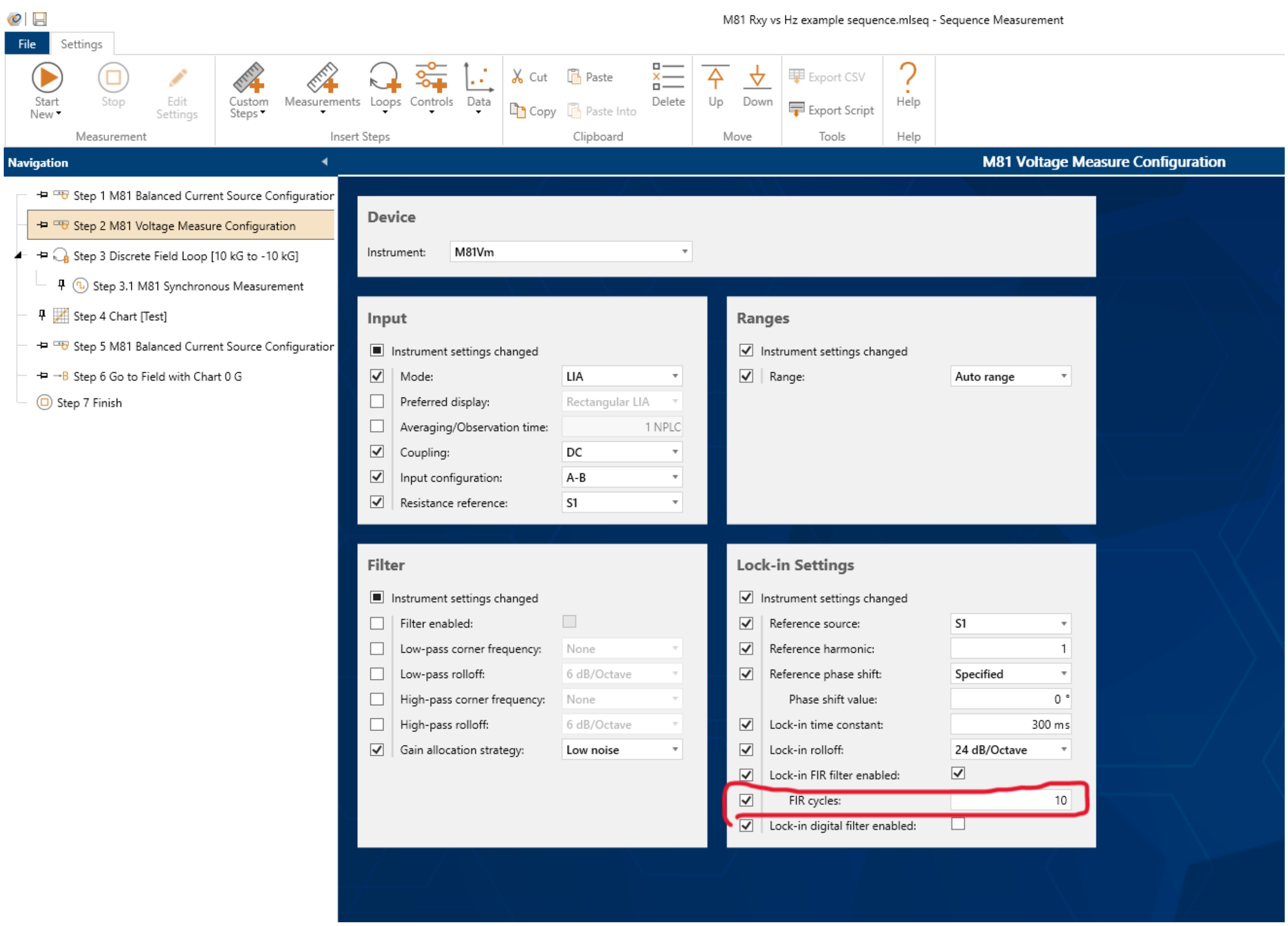
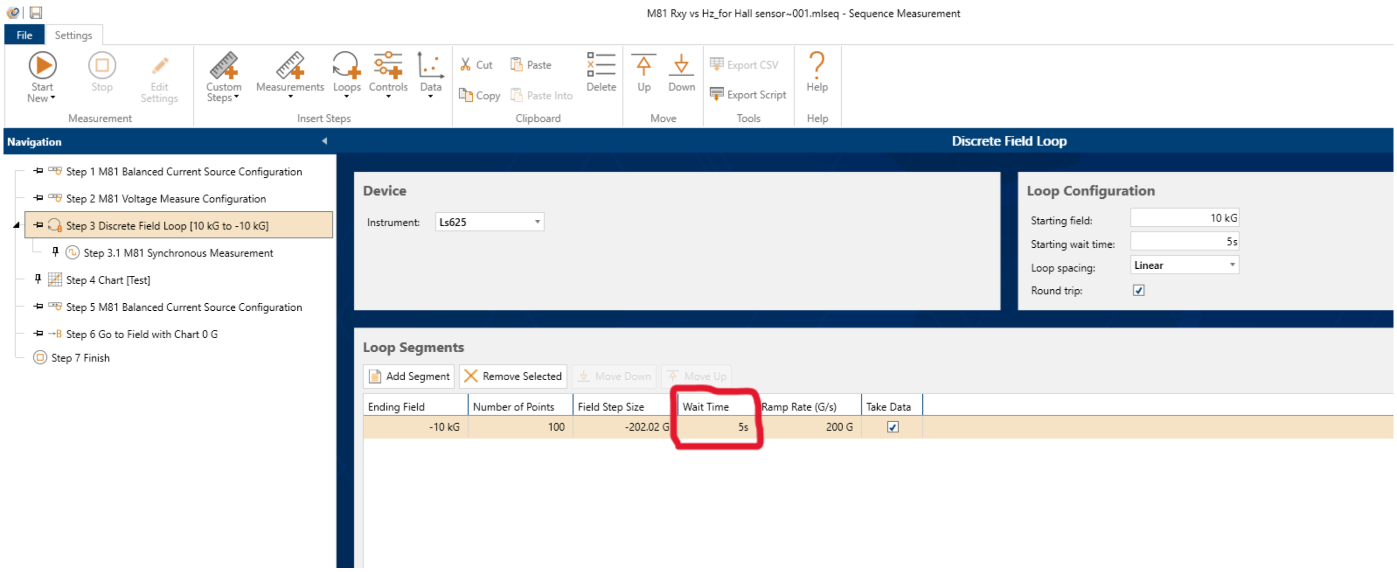


Figure 9. Step response of IIR filter.



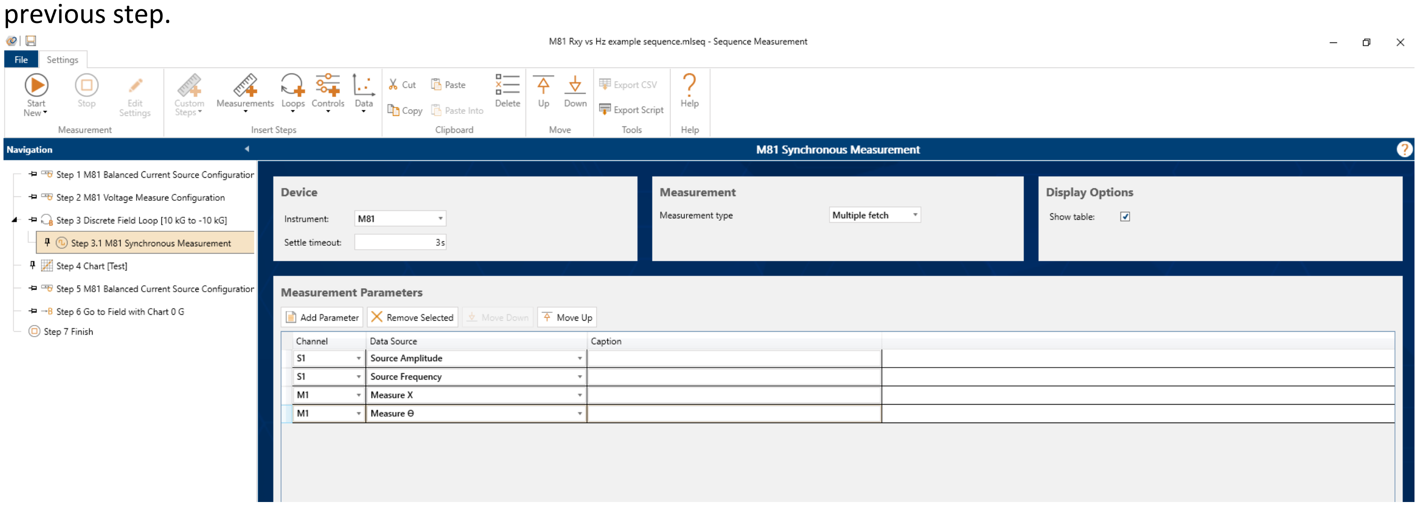
Setup 2. Voltage measure configuration

6. Add a control loop to set magnetic field for the magnetic field scanning. Go to Loops -> Field -> Discrete Field Loop. Choose the starting field and use “Add Segment” to add the ending field. Allow Round trip if wanted to collect extra data (hysteresis etc.).
7. As shown in setup 3-1, we start the measurement at the starting magnetic field at 10 kG (1 T), and 5 s for the initial field to be stabilized before starting the measurement. The ending field is set to be -10 kG (-1 T), and a loop scan between 1 T to -1 T would be established when the Round trip button is checked. Note that number of points are manually input, and field step size is calculated based on the scanning field range and the number of datapoints. Also manually input the ramp rate (G/s) and wait time at each field. Please **do NOT exceed the maximum ramp rate of 840 G/s.** Also note that **the wait time at each field (circled in red) should be at least one cycle of t_{settle}, so that the signal is well settled and recorded**. Here we choose wait time 5 s at each field.



Setup 3-1. Magnetic field configuration

8. Add in data collection step by Measurements -> M81 Source/Measure -> M81 Synchronous Measurements, as shown in setup 3-2. Use “Add Parameter” to add in data to be collected. Drag this step into the field loop created in the previous step.

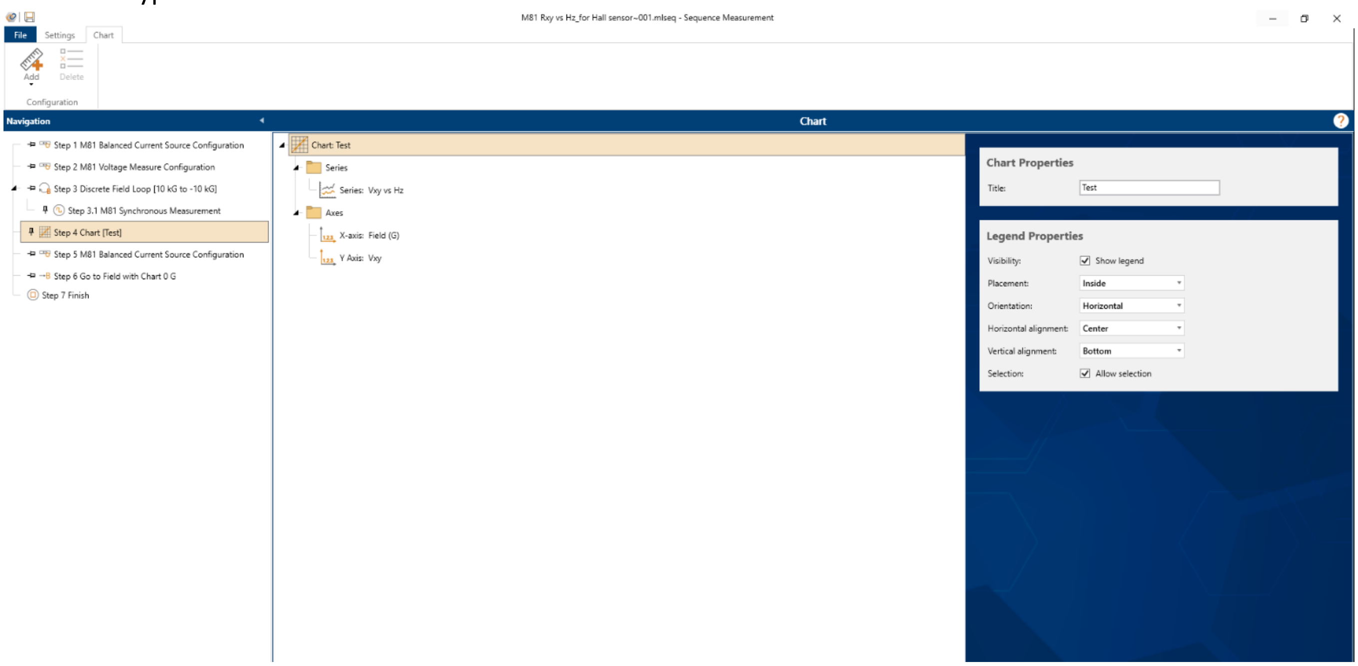


Setup 3-2. Data collection configuration

9. Now, outside the voltage loop, create a chart to visualize what data this experiment has collected. As shown in setup 4, this is done by Data -> Chart. Click on “Series” folder icon under “Chart: X vs. Y” and on the top left of screen, choose “Add Series” to add the plot. For each chart(series) in the same step, we need to set corresponding X-axis and Y-axis

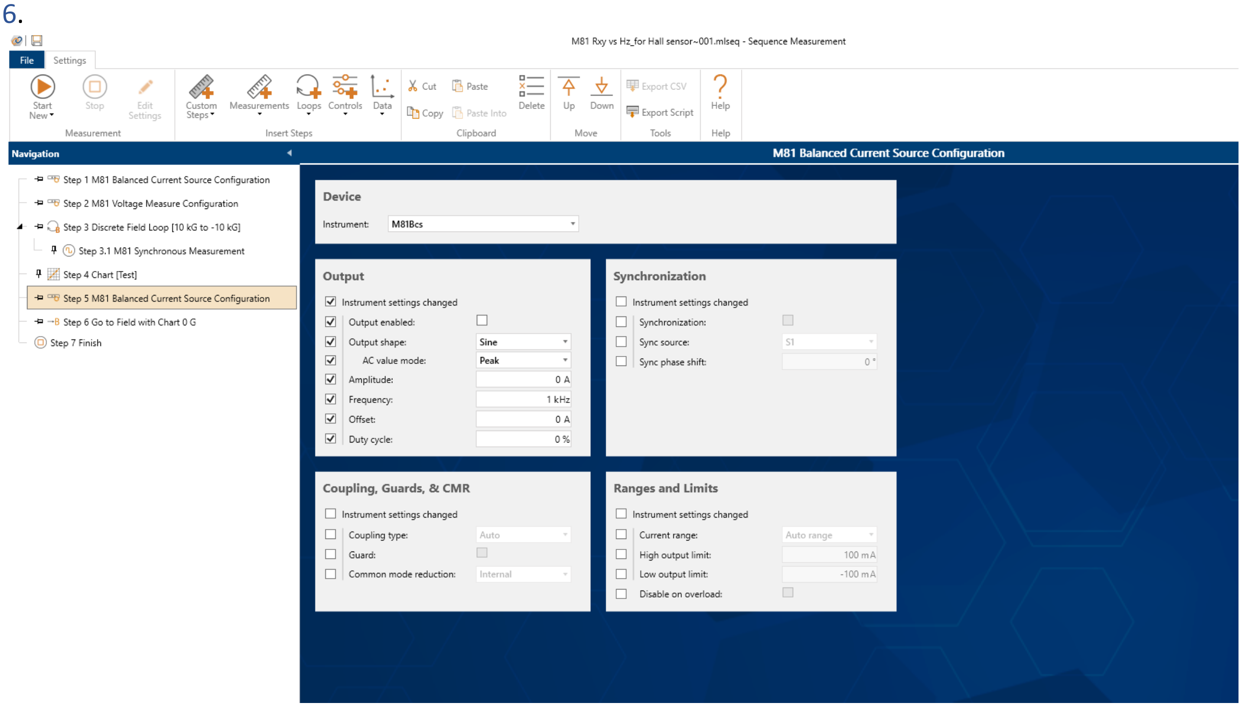
for different types of data. These datatypes should correspond to the data to be plotted in the "series". In the example sequence, data to be plotted is the LIA measurement results from previous loops. "Measurement Results" should be set to the step which measures all the data. Then choose M1 X or M2 X for Y-Axis data. For X-Axis data, choose "Measured Field".

10. The example sequence plots voltage measurement from M1 and M2 against field in separate steps. These two have same data types in both X and Y axes, so they have one similar pair of X and Y axes configuration. For X-axis, choose field as datatype and choose double for Y-axis.

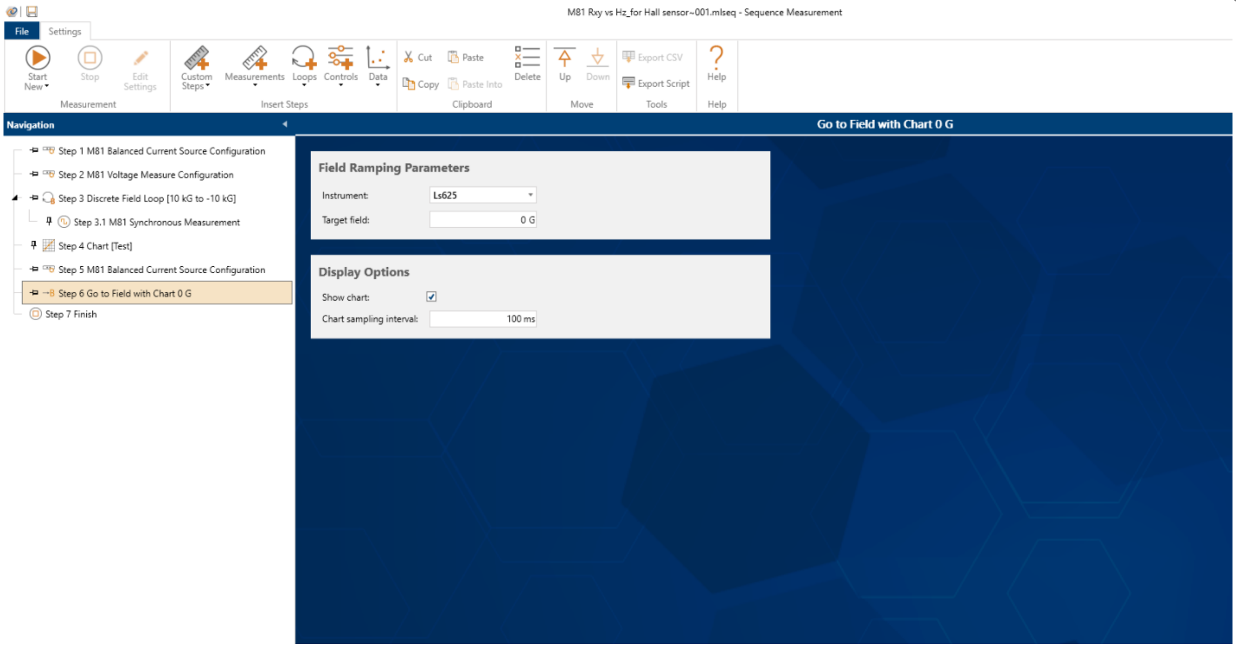


Setup 4. Chart visualization configuration

11. After setting up chart, add steps to turn off balanced current source, and set field to zero, as shown in setup 5 and setup 6.

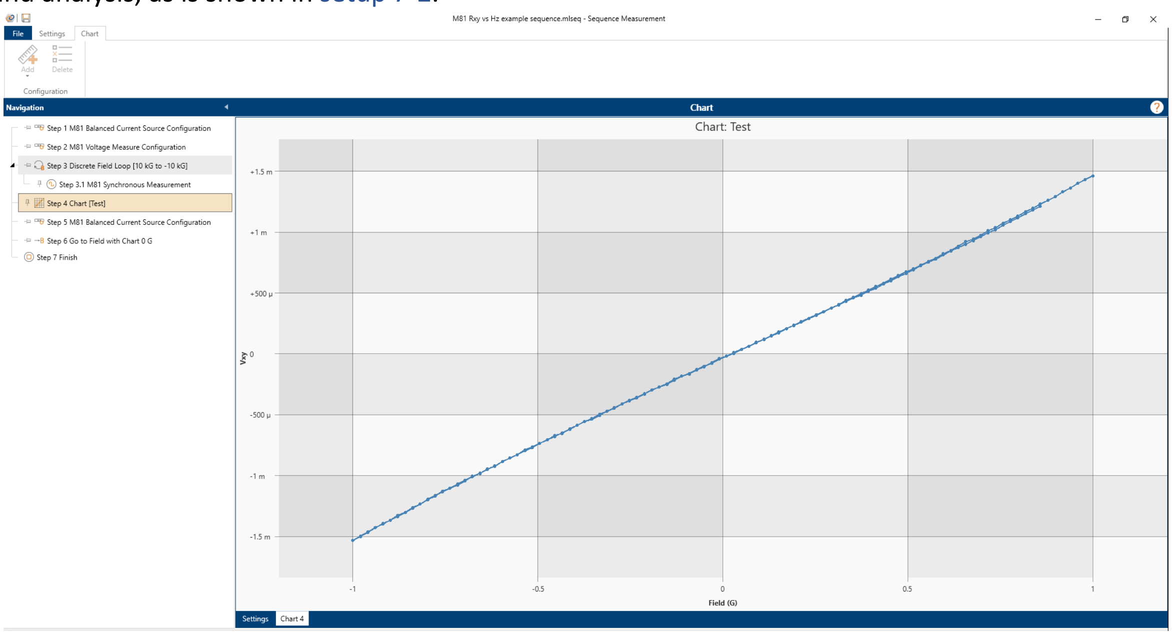


Setup 5. Turn off current source

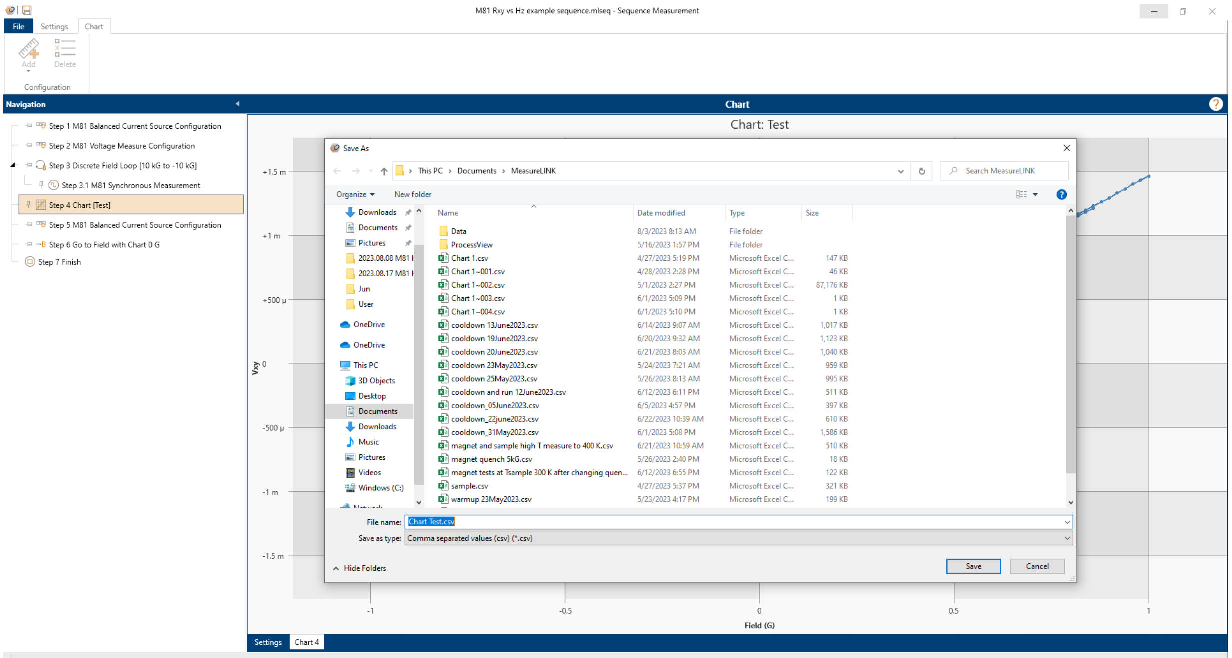


Setup 6. Set magnetic field to zero

12. Click Start to run the sequence. After the sequence is finished, the measured chart will be generated automatically, as shown in setup 7-1. Remember to right click the mouse and select "Export CSV" to save data as the .csv file for future plotting and analysis, as is shown in setup 7-2.



Setup 7-1. Generated plot after the measurement



Setup 7-2. Export datafile for plotting and analysis