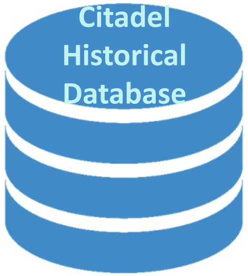
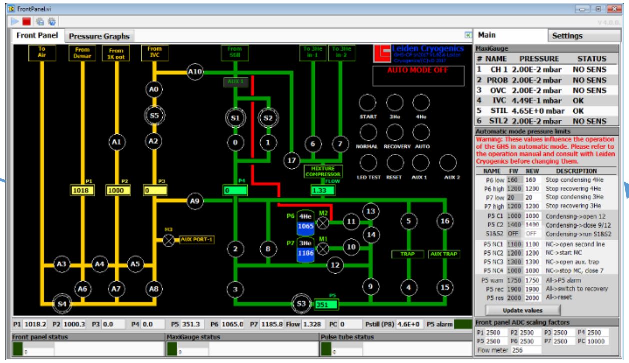
Experiment 1: Hardware Overview



Front Panel (FP) Valve Controller

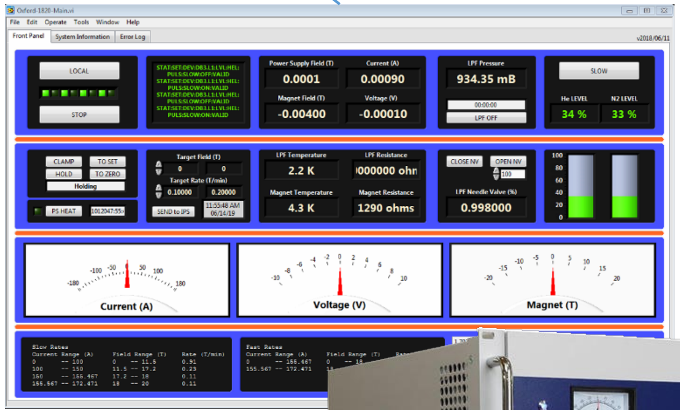


LabVIEW Instrument (FP)

Dilution
Refrigerator
(T=20mK)

Temperature Controller (TC)

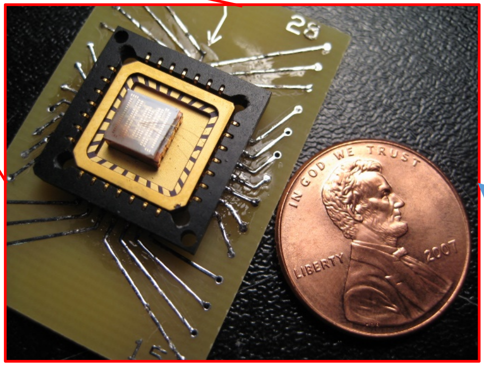
LabVIEW Instrument (TC)



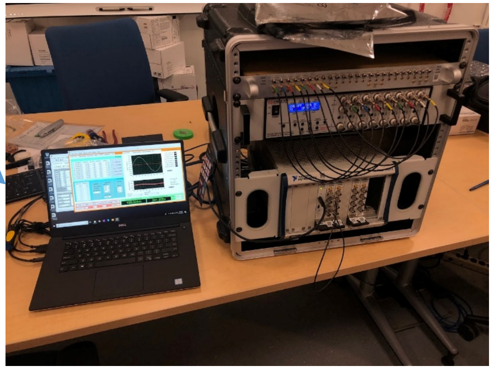
LabVIEW Instrument
(PS)

Superconducting
Magnet Power Supply (PS)

Superconducting
Magnet



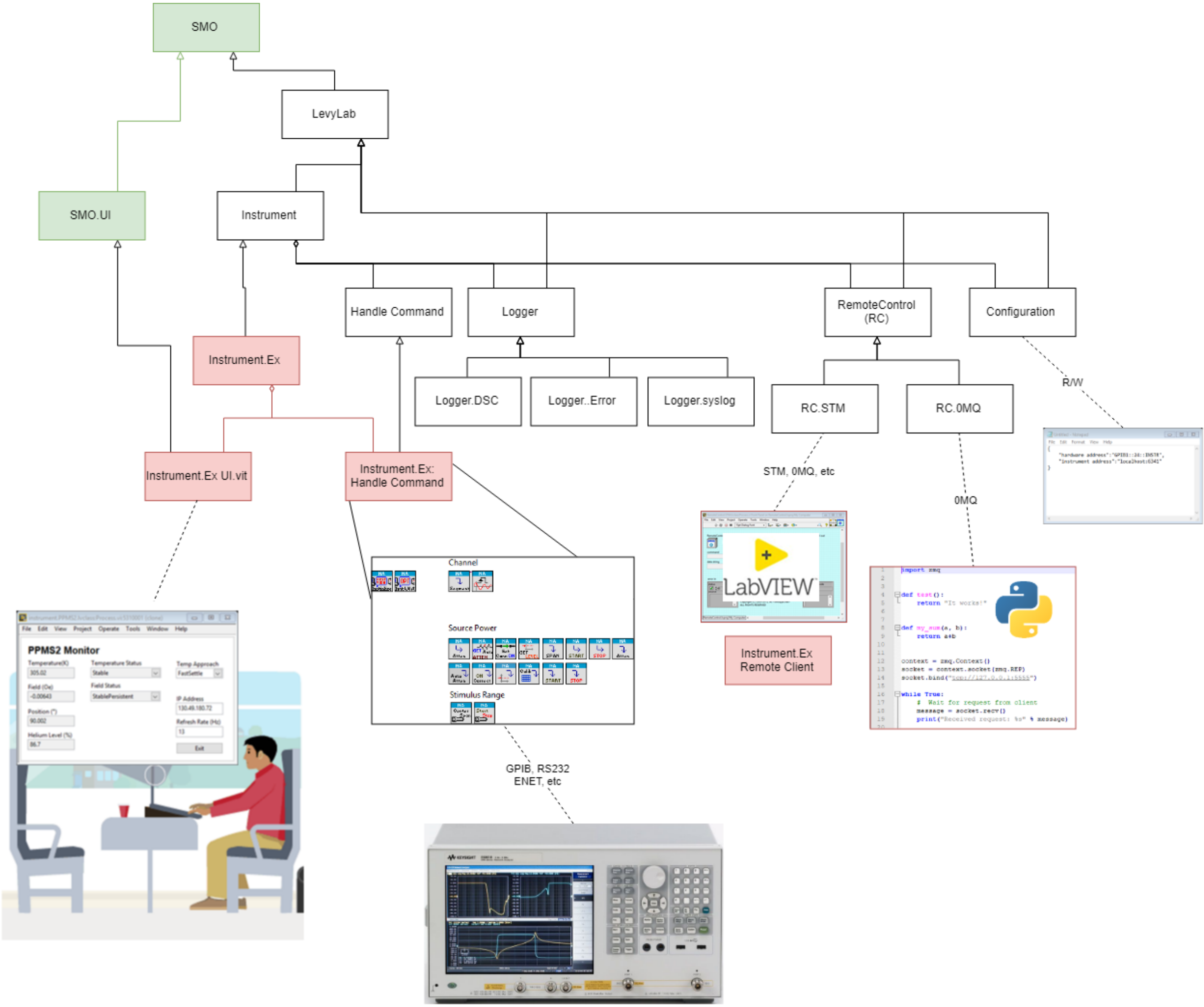
sample



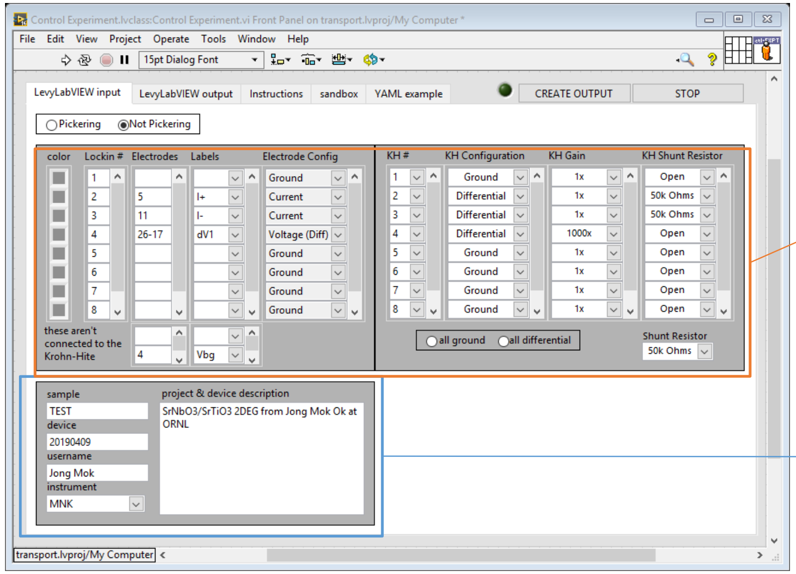
Data Acquisition (DAQ)

Experiment 2: LabVIEW Instrument

- A LabVIEW Instrument has the following responsibilities:
  - Know how to communicate with a piece of hardware (drivers)
  - Poll the instrument for its settings and log to a database
  - Open an API for external programs (e.g through cross-platform protocol such as 0MQ)
  - Provide a UI (optional but probably desirable)

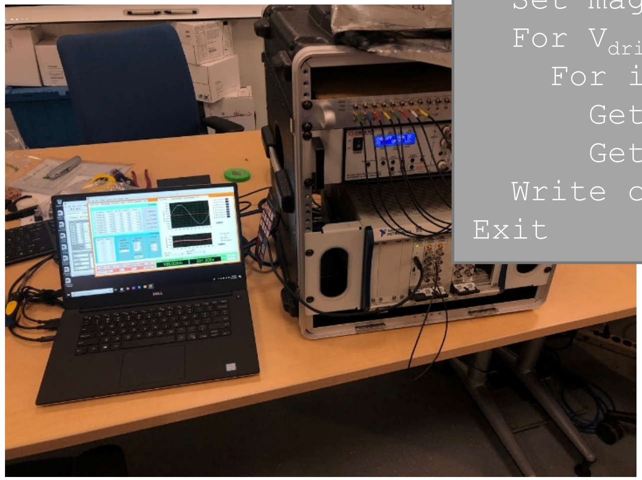


Experiment 3: An "Experiment"



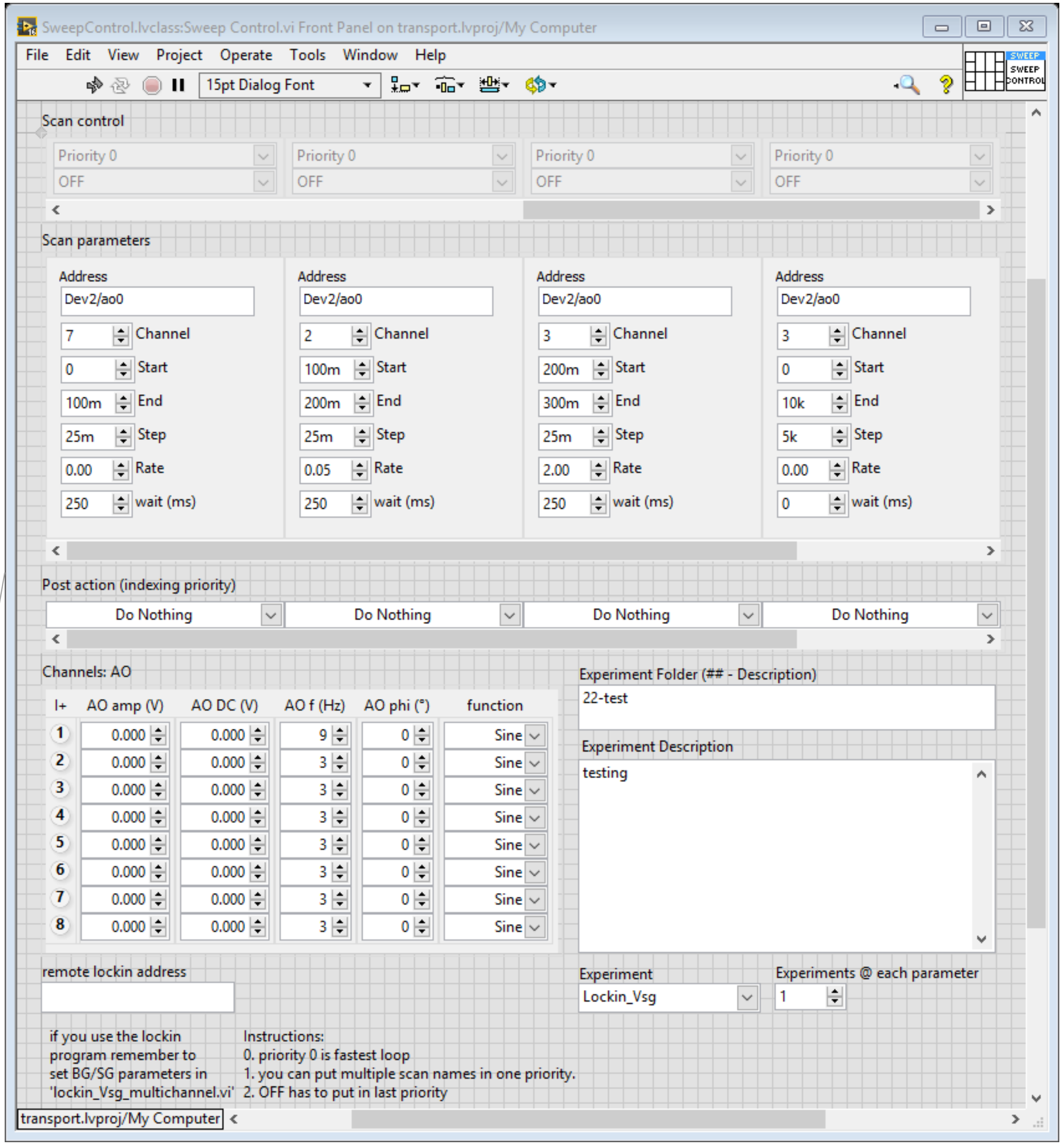
1. Configure wiring and voltage and current amplifiers

2. Define global settings such as sample name and description.



3. Define experiment

```
Initialize some stuff
For B = 0 to B_max:
  Set magnet = B
  For V_drive = 0 to V_drive,max:
    For i = 0 to N
      Get current_i
      Get voltage_i
  Write current and voltage to File_B.itx
Exit
```



Experiment 4: ITX (Igor Text File)* Description 1

```
IGOR
X// Date: 1/12/2017 8:40 PM
X// sweep B: 3.5T to 9.5T, 0.06 T/min
X// large axis: 147, small axis: 257 (20 deg)
X// sweep Vsg: 0mV to 120mV 250uV step
X// Vbg=0.3V
X//
X// tc=0.3s
X// order=4
X// 60 Hz filter OFF
X//
X// lockin:
X// 0: 1, voltage
X// 1: 2, current, 100uV AC 240uV DC, 13 Hz
X// 2: 3, voltage
X// 3: 4, voltage
X// 4: 5, current
X// 5: 7, voltage
X//
X// KH gian=100x, shurt resistor=50kOhm
```

- First line is always "IGOR"

- Metadata begins with X//
- This section should describe the experiment that was done
- This one describes that 1. B will be swept from 3.5 Tesla to 9.5 Tesla at a rate of 0.06 Tesla/minute. 2. Vsg will be swept from 0 mV to 120 mV in 250 uV steps.
- Each file will be one Vsg sweep. The folder will contain data between B = 3.5 T and 9.5 T. And as many Vsg sweeps that could be taken while B was changing.

- This section describes how the lockin was configured.
- The lockin measures current or voltage on the sample in response to some source voltage stimulus.
- There are typically 8 lockin channels (not all need to be used) and there are X and Y for each, which are in-phase and out-of-phase, respectively, with the source voltage.
- The information here means:
  - Lockin0 (connected to electrode 1) measures a voltage
  - Lockin1 (connected to electrode 2) sources a current using a 100 uV source voltage at 13 Hz
  - …
  - Lockin5 (connected to electrode 7) measures a voltage

*Described in more detail on p.II-131 here: https://www.wavemetrics.net/doc/igorman/II-09%20Data%20Import%20Export.pdf

Experiment 4: ITX Description 2

```
WAVES/D/N=(481) 'time.SA02836H.20170110.000002'
BEGIN
3.567116343758267E+9
3.567116353762839E+9
3.567116353912848E+9
3.567116354064857E+9
3.567116354215865E+9
3.567116354440878E+9
3.567116354590887E+9
3.567116354818900E+9
```

- Here starts a wave of size 481. This one is the time
- (seconds since epoch time (1904 I think))

- Sample code: SANNNNNL.YYYYMMDD
  - SA: Sample
  - NNNN: 5 digit sample number
  - L: one of 16 “canvases” on a particular sample
  - YYYY: Year
  - MM: Month
  - DD: Day

```
3.567116453997572E+9
3.567116454222585E+9
3.567116454298590E+9
3.567116454448598E+9
3.567116454599607E+9
3.567116454824620E+9
3.567116454986629E+9
3.567116455136638E+9
END
```

- End of the wave

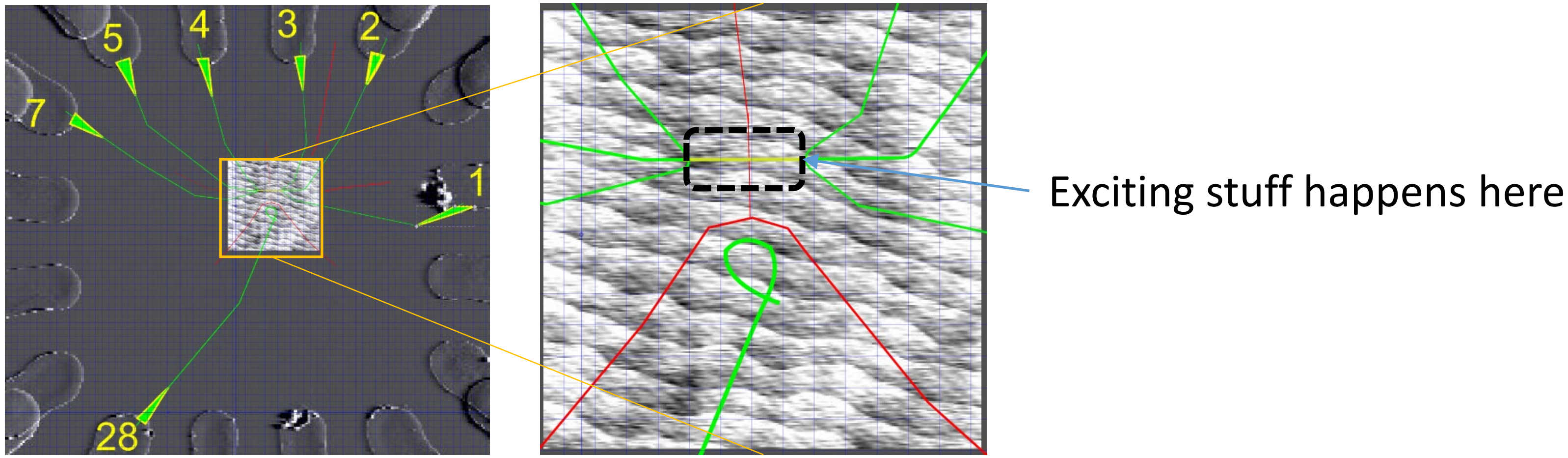
```
WAVES/D/N=(1) 'B.SA02836H.20170110.000002'
BEGIN
3.801700000000000E+0
END

WAVES/D/N=(481) 'X0.SA02836H.20170110.000002'
BEGIN
100.586757640980660E-6
100.562881961642580E-6
100.554882945805970E-6
100.548795103440390E-6
100.541729931379820E-6
100.540689133795410E-6
100.545901069673990E-6
100.563244064805010E-6
100.589700051043400E-6
```

- Wave of size 1 showing the B field for THIS file

- Wave for In-phase (X) Lockin0

Experiment 5: Data Processing 1

1. Look at experiment notebook for sample SA02836H.20170110. There should be a description & diagram of the device:

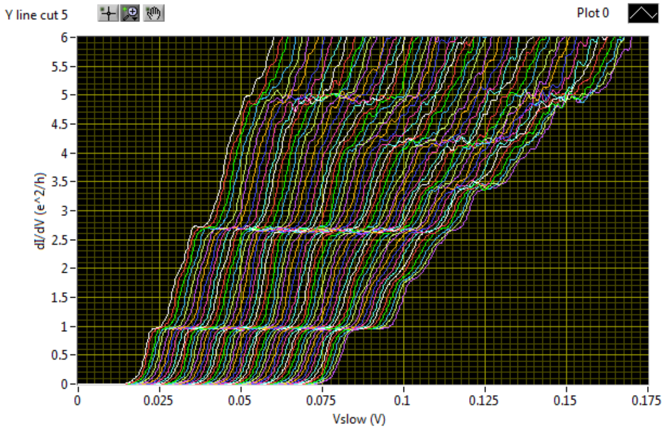


2. We want to plot the Four terminal resistance of the exciting section. So we need a current and voltage on each side of the device.
2a. The metadata tells us electrode 2 and 5 were current source and drain. Then pick a voltage on each side, e.g. 3 and 4, 1 and 7, 3 and 7, or 1 and 4.
2b. Now go back to the metadata again and decipher which lockins those correspond to*. Let's choose electrodes 1(V), 2(I), 4(V), 5(I), which are lockins 0(V), 1(I), 3(V), 4(I).
3. The 1st dependent variable is V_{sg}. The 2nd is B
4. Read the waves X0.*, X1.*, X3.*, X4.*, Vsg.*, B.* from each file. Calculate $R_{4T} = \frac{V_1 - V_2}{I} = \frac{\mathrm{X3} - \mathrm{X0}}{\mathrm{X4}}$. You now have R_{4T} vs V_{sg} for each file, each of which is one value of B.

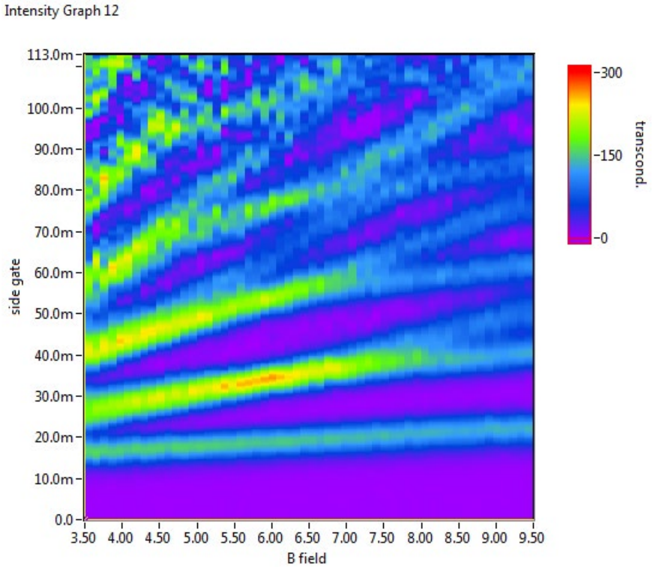
I will not be offended if you roll your eyes at this point

Experiment 5: Data Processing 2

5. We also typically calculate four terminal conductance $\frac{dI}{dV} = G_{4T} = \frac{1}{R_{4T}}$ and expressed in units of e^2/h (electron charge squared/Planck constant). Each line in the next graph is data from one file:



6. Calculate the transconductance $\frac{dG_{4T}}{dV_{sg}}$ by numerically differentiating each curve. We typically plot this as an intensity plot vs Vsg and B, with color representing the transconductance.



Experiment 6: Next-Level Analysis

7. Use R magic to analyze locations of splittings/crossing/avoided crossings as a function of B and Vsg