

# Superconductor Transition Measurement Hints

## WARNING

*Use extreme caution when handling the superconductor lead wires.*

- **Gently** push the cable through the brass cap, being careful that you don't damage the small connectors on the end of the cable and that you don't kink or unnecessarily flex the leads.
- Put a **thin** coating of the anti-seize compound on the threads of the superconductor assembly before you screw it into the aluminum heater block. This will ease the process when you have to remove the superconductor from the heater block.
- Screw the superconductor assembly into and out of the heating block using a *large* screwdriver in the back slot.

The small yellow or gray screwdrivers are *not appropriate* for inserting or removing the superconductor from the block.

**Never** twist it in or out by the wires.

- It is usually good to use the screwdriver to hold the superconductor assembly stationary with respect to the room and rotate the aluminum heater block when you assemble or disassemble them. This will avoid the problem of wrapping the wires around the screwdriver and reduces the likelihood that you will break one or more wires during the assembly/disassembly process.
- **Never, never, NEVER**, bend the superconductor lead wires when frozen.

## 1.0 Some hints on making the superconductors work

1. When you build a constant-current supply for the four-lead measurement of the resistance, it should have an output current in the range of 10-50 mA, not to exceed 100 mA.

**Note:** this constant-current supply is *in addition* to the supply you already built. When you finish, you will have one supply providing 90-110  $\mu\text{A}$  for the temperature measurement diode and one providing 10-50 mA for the superconductor resistance measurement.

Since you used a TL3472 op amp, you will use the second amplifier in the package for the second supply. The voltage divider providing the voltage reference on the non-inverting input can be connected to both amplifiers if you wish.

When you think your supply is ready to go, you should check both currents simultaneously. The best sequence is to connect a meter to the  $100\ \mu(A)$  output and note the value. Then connect a different meter to the new  $10\text{-}50\ (mA)$  output. The output of the low current supply should not change significantly. If it does change, the cause is usually a missing capacitor or cold solder joints on the capacitors.

2. First, verify that your superconductor isn't already broken.
  - (a) Using an ohmmeter, check the resistance between the black, white, red, and orange leads. Check *every possible combination*. It should be about  $1.5\text{-}2\ \Omega$  between any two leads (most of that is contact resistance).
  - (b) When you connect the mA-range constant-current supply to the black and white leads on your superconductor sample, you should be able to read something around a mV on the red and orange leads (using a voltmeter is adequate for testing).
  - (c) Use the diode-check setting on your multimeter to verify that the diode is functioning and that there are no broken leads. Most multimeters will read the voltage across the diode when it is forward biased (this should be about  $0.5\ \text{V}$ ) and overload when it is reverse biased. The violet lead is the connected to the diode cathode.
3. Your analog input Express VI should be set to a range that is consistent with the voltage you measured in the previous step for the superconductor voltage. Since that was done at room temperature, the voltage measured with the voltmeter should be very near the maximum for the experiment. It is wise to specify a range that is slightly larger than this maximum voltage. *Be sure to keep the voltage range bipolar*. LabVIEW will set the range for the hardware to the smallest available setting that is greater than or equal to your specified range.

It is best to keep your range as small as possible while allowing for the expected input signal. This will provide the best resolution for your measurement.
4. Remember that the range on the Express VI for the diode channel is supposed to be 0 to about  $1.5\ \text{V}$  (the upper voltage needs to be large enough for the voltage you measured when calibrating the diode in LN; this will likely be slightly more than  $1\ \text{V}$  for your diode with the  $100\ \mu\text{A}$  supply).

With the USB-6221 the voltage range is slightly greater than what you specify. If you specify  $\pm 1\ \text{V}$  it will be able to properly read voltages to about  $1.02\ \text{V}$  without truncating the data.

5. You will be using the A/D converters to read two different voltages for these measurements. These two voltages are very different in magnitude (a few mV compared to roughly  $1\ \text{V}$ ). The analog inputs have only one A/D converter

and the selected inputs are sequentially connected through an analog switch to that single converter. Due to source impedance, resistance in the analog switch, and capacitance from the various components to ground, the voltage at the input to the A/D converter will not change immediately to the new value. It is advisable to configure your analog input VI to allow adequate time for the voltage to settle before recording the value.

There is a chart in the datasheet for the USB-6221-BNC (the board we are using) indicating the approximate settling time to get within  $\pm 1$  LSB (within one A/D converter level) for various source impedances. For example, with a  $10\text{ k}\Omega$  source impedance this comes out to about 30 to 40  $\mu\text{s}$ .

As noted in our discussion of analog measurements during the LabVIEW exercises, the default settling time allowed by the USB-6221-BNC is 14  $\mu\text{s}$  if the acquisition rate is slow enough. Maintaining this settling time puts a strong limit on the rate at which you can acquire these two channels in this experiment. This time is only possible if your sample rate is less than  $1/(n * 14 * 10^{-6})$  samples/s where  $n$  is the number of channels being acquired. For our case with two channels, this would give a maximum sample rate of 35 kS/s.

It would be useful to look at the National Instruments document “[Is Your Data Inaccurate Because of Instrumentation Amplifier Settling Time?](http://www.ni.com/white-paper/2825/en/)” (<http://www.ni.com/white-paper/2825/en/>).

For example, if a  $500\text{ k}\Omega$  resistor was used for R3 in your supply for the temperature measurement diode, The effective resistance of the diode is  $10\text{ k}\Omega$  (1.0 V at  $100\text{ }\mu\text{A}$ ). If this is much smaller than R3, the effective output resistance is very close to  $10\text{ k}\Omega$ . If it is comparable to the size of R3, you will use the parallel combination of the diode and R3 for the output resistance. As noted above, the required settling time is about 30 to 40  $\mu\text{s}$ .

**Strong Recommendation:** Since you can't adjust the interchannel delay with the DAQ Assistant VIs, you will likely have to do something else to ensure that your signals are sufficiently settled to get accurate measurements. As noted above, we need probably 2 to 3 times as much settling time as that provided by the default period. One way to increase the settling time is to sample the same channel several times in a row and use only the last value measured. You may have to experiment with how many times to sample a given channel to get the desired accuracy.

As an example of how to do this if you are sampling two channels, you will have multiple “channels” defined in the DAQ Assistant but several successive channels will be set to the same physical input with the same input range. For instance, if you want to sample AI0 3 times and AI1 3 times you would set the channel list to be:

```
Dev1/ai0  
Dev1/ai0
```

Dev1/ai0  
Dev1/ai1  
Dev1/ai1  
Dev1/ai1

Then to get the settled values from those provided by the `DAQ Assistant VI`, you would set the `From DDT` (From Dynamic Data Type) function to give you channel 2 for ai0 and 5 for ai1 (the channel numbers start with 0).

Note that you still require a sample rate that will allow the required settling time. Since we are now acquiring 6 channels, the maximum sample rate to still have  $14\ \mu\text{s}$  settling time would be about  $(6 \times 14\ \mu\text{s}/\text{sample})^{-1} = 11.9\ \text{kS/s}$ .

6. You also need to be sure that the inputs on your data acquisition hardware are properly configured. Below each input connector there is a switch labeled `FS` or `GS`. `FS` stands for floating source and indicates that there is no ground reference provided by the signal source. `GS` stands for grounded source and indicates that there is a ground reference provided by the signal source.

The power supplies used for the constant current circuits all have the ground terminals connected to chassis ground. Since the source is grounded, you should select the `GS` position for the diode voltage measurement.

You should also select `GS` for your superconductor voltage. The main reason for this is the return side of the current to your superconductor is connected to ground through the tan  $+15/-15/+5\ \text{V}$  power supply (the current return is the black wire). If you connect the superconductor voltage measurement cable to a ground reference, some of the current through the superconductor will flow through that connection and the contact resistance will become important.

7. Most of the computers have an intrinsic offset voltage in the analog inputs (usually a few  $\mu\text{V}$  on the most sensitive scale). The best way to remove this is to
  - (a) take the superconductor to LN temperature
  - (b) disconnect the white wire from the superconductor adapter cable
  - (c) measure the voltage across the superconductor (red/orange cable) using the data acquisition hardware
  - (d) reconnect the white wire on the superconductor adapter cable.

Ideally this voltage is the intrinsic offset, and you can then subtract this voltage from the measured voltage to get the correct voltage.

Note that if you have any signal crossover between the diode and the superconductor this offset will appear to change between room temperature and LN temperature because of the change in diode voltage from about  $0.37\ \text{V}$  to slightly greater than  $1\ \text{V}$ .

If you disconnect the black wire from the adapter cable for a significant period, you may see the voltage drift. This is because the input is now floating (you

don't have a ground reference) and it will sometimes read the voltage difference incorrectly (recall the  $\pm 11$  V limit from the specification sheet).

8. You should save *at least* 6 significant figures in the superconductor voltage or superconductor resistance data. The best format to use is `%.6e` that saves 6 figures in exponential format. With `%.6f`, you will lose resolution when the resistance is near zero (loss of resolution is generally considered a bad thing).

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