

Cryogenic Wiring Guide

Wire Insulation

Most issues seen with the Montana Instruments Cryostation relating to wiring can be connected to faulty wiring due to insulation problems. Oftentimes the insulation is worn away in high-use areas, like under the thermal clamps, and by use of sharp edge tweezers. The insulation is very fragile and can be as thin as 2.5um and can be scratched off the wire very easily. The best rule of thumb is to use Teflon tipped tweezers to position the wires around the system components and operate under a microscope.

Also, it is generally good practice to avoid using Teflon tape as a scratch protector under the thermal clamps. The thermal isolation can lead to higher base temperature on the platform due to the poor thermal conduction of the material. If electrical isolation is needed, a piece of Kapton tape can be wrapped around the RF coax at the clamp or placed under the RF coax cables.

Electrical Isolation

For sensitive electrical measurements it is very important to isolate the various measurement leads from potential sources of electrical and even thermally driven noise. If there are sensitive electrical measurements on a set of leads close to a noisy source lead, like a voltage pulsing line, there can be some non-negligible crosstalk between them. It is important to separate these types of sensitive measurement lines from the potentially noisy sourcing lines as much as possible. Furthermore, sensitive voltage-based leads should be separated from current based leads. Due to variable voltages that can be created by high current sources nearby, there can be significant voltage gradients created by thermal loads. This phenomenon is related to the thermoelectric effect. For this reason, sensitive voltage lead heat sinks should be separate from current lead heat sinks.

Grounding

Improper grounding is most likely the biggest source of noise in a sensitive electrical measurement. Keeping a good ground is important to insure nearby metallic masses do not build up charge and offset a local voltage. It is a general rule of thumb to only have a single ground point for all instruments used in an experiment. This will keep “ground loops” from disturbing signals. A ground loop can simply be thought of as a common nonzero resistance connection between circuits that acts to pull up the base voltage from a true ground on each circuit. This will drive a current through the circuit created between the separate instruments. This will disturb each measurement circuit due to the electrical connection between them.

One common problematic issue occurs when several instruments are plugged into different power strips on different measurement racks. One easy solution is to have all the instruments isolated and have a single common earth-ground for the entire system. However, avoid connecting very sensitive electronics, like a Nano voltmeter, to the same ground as other instruments and high-power equipment. One method to overcome ground loops in such a case is to use what is called common isolation or using an ammeter with high common mode impedance to ground. This will act to reduce the driven currents in the ground loop.

Twisted Pair

If there are parallel common mode lines carrying an equal but opposite direction signal next to an AC current source lead, you can expect some crosstalk between the two due to induced currents in the common mode lines from the AC magnetic field. This is due to the open area between the common mode lines creating a time changing flux, which can be shown from Maxwell's equations will cause an induced current.

One way around this condition is the method of the twisted pair. The common mode lines can be wound together in a twist. This condition creates the case of several smaller areas of canceling induced currents of different signs. If the twists are close enough, the induced crosstalk can be kept to a negligible amount, and this should be used anytime where sensitive DC lines are in a region of AC source lines. A good rule of thumb for the twisted pair distance is to have the separation between the twists to be < 20 wire diameters, and a good method to create a twisted pair is to use a power drill with a fixture to hold two wire ends and wind with a constant speed.

Minimizing Thermoelectric Effects

In the case that there are sensitive voltage measurement leads near current leads which are both sharing a heat sink, there can be a non-negligible voltage difference created due to the temperature gradient between the lines. This is known as the Seebeck effect and can be imagined as the free charge carriers moving in the direction of the warmer side of a temperature gradient. One way around such effects is to use a low frequency AC signal instead of a DC signal whenever possible.

Wiring with AC signals

When using AC voltage and current lines in a single measurement, one can experience strange phase shifts due to unwanted stray capacitance between the two groups of leads. Therefore, try to separate the voltage and the current lines as much as possible to reduce such effects. Always use RF-filters whenever possible within an AC experiment. If you are going to make custom passive electrical components to be used within a RF experiment, make sure the shield-to-shield connectors are watertight to keep out RF radiation. If there are also DC measurement leads within the RF environment, make sure to follow the twisted pair method from the previous “twisted pair” section.

Thermal Lagging/Anchoring

To reach the lowest base temperature possible on the cryostat platform it is important to keep the external heat load to a minimum. This of course includes the potential heat load from the incoming wire connections from the thermometers and heaters due to Joule heating. To keep this load low, the wires can be thermally connected to a cold point with sufficient cooling power to pull heat from the wire and bring all points after the lag points to this common temperature. This technique is called thermal anchoring or lagging, which can be accomplished by wrapping the wire around a copper bobbin or pin the wire under an anchor point like a thermal clamp.

For instance, if you have a resistive thermometer with copper electrical contacts coming in from room temperature, to connect the thermometer to a 4K platform and not raise the temperature of the platform, you can lag the wire at a bobbin at the 30K stage with several wraps along with varnish to achieve the effect. Also, you could lag the end of the wire to the 4K platform before a measurement point to keep the measurement free from systematic heating artifacts.

However, if there is no room for the bobbin type connection, one could use a higher resistance metal like Phosphor/bronze with a much lower thermal conductivity and simply lag the wire under a smaller thermal clamp and leave sufficient length after the lag point to create a condition of high thermal gradient. The idea behind this is that due to the low thermal conductivity, the heat coming in from the 30K end along with cooling power at the lag point at the 4K point, an equilibrium condition is maintained with the needed thermal gradient of (30K-4K). Below is a simple calculus of the problem suggested:

$$\delta Q_{out} = k(T)A \frac{\delta T}{l} \quad Q_{out} = \frac{A}{l} \int k(T) \delta T$$

The first relation is just the well-known Fourier's law in differential form for thermal conductivity given a wire with a known cross-sectional area (A) and a thermal conductivity constant (K), which due to its temperature dependence, will have to be integrated down the length of the wire (second relation). The crucial idea here is to choose a length of wire, with a given cross sectional area, which holds the Qout lower than the cooling power of the platform. This all means that even with a small lagging surface area, a thermometer can still be mounted on a 4K platform without heating the platform above 4K by giving it a few inches of lead between the 30K and 4K lagging points.

To analyze the conductivity completely, one would calculate the integral of the thermal and electrical resistance for the wire length based on the temperature at each point on the wire. To simplify that, you can assume that the resistance is roughly linear, and the result will be approximately right. Below is a table of the electrical resistance and thermal loss, based on a 4" wire segment from room temperature to the radiation shield and another 4" from the radiation shield to the sample.

For electrical resistance:

Wire Material	AWG	300-30K leg, 0.1m long resistance (ohms)	30-3K leg, 0.1m long resistance (ohms)	Total Resistance (ohms)
Copper (C110)	34	0.08	0.01	0.1
Phosphor Bronze	36	1	0.87	1.9
Manganin	36	3.5	3.7	7.2

The corresponding thermal loss:

Wire Material	AWG	Diameter (mm)	Thermal load on shield (mW) 300-30K leg, 0.1m long	Thermal load on sample (mW) 30-3K leg, 0.1m long
Copper (C110)	34	0.16	26.7	3.5
Phosphor Bronze	36	0.127	1.03	0.02
Manganin	36	0.127	0.48	0.01

If your circuit can tolerate a 2 ohm electrical resistance per wire, then using Phosphor Bronze wire will introduce only 20 microwatts of heat per wire. Note that if the wire was not lagged, there would be over 1mW of heat load on the sample (the sum of the two loads).

Below are a few useful charts with the thermal and electrical conductivity for commonly used wires in the system.

Table 1. Thermal Conductivity (W/(m K))

Wire Type	300K	30K	4K
Copper (C110)	400	1000	300
Phosphor Bronze	48	12	1.6
Manganin	22	6	0.5

Table 2. Electrical Conductivity (Ohms/m)

Wire Type	AWG	Resistance (ohms/m) 300K	Resistance (ohms/m) 4.2K
Copper (C110)	30	.32	.003
Copper (C110)	34	.81	.0076
Phosphor Bronze	32	4	3.3
Phosphor Bronze	36	10	8.6
Manganin	30	9.7	8.6
Manganin	36	39	35

INSTALLATION OF WIRING

Basics

Installing small gauge wire correctly can be a very difficult task and some might even consider it an art. As mentioned before, there are many issues that must be dealt with when installing fine gauge wire. These issues include mysterious shorts, connectivity problems, heat loading, and the introduction of electronic noise. There are a few things you can do to ensure a good degree of success.

- When creating new wiring harnesses with soldered pin-ends, always take care to only take the smallest amount of insulation needed for the lead-ends. This could lead to a future short which could be very difficult to trace.
- Check the connectivity of the new wire harness and all electrical resistive components with a voltmeter before connecting to a larger ensemble of components in the measurement system.
- Make sure not to introduce a material into the sample space that can outgas harmful contaminants. Things not to put into a vacuum chamber include, but are not limited to: plastics, PVC, paints, zinc, flux, lead, and cadmium.

Practical Lagging Techniques

The idea with lagging is to achieve a maximal surface area contact between the warm and the cold surfaces. This is only achieved when using wire with the use of something like varnish and string (dental floss). Before the application of the wire to the cold surface, make sure to thoroughly clean the cold surface with alcohol. Sometimes a compression spring mechanism can be employed to press the wire or other material to be lagged down onto the surface for enough contact force to cool the warm object.

Soldering Basics

When soldering small wires and small pins, get used to working under a microscope and using small precise tweezers. Always “tin” the tip of the chosen soldering tip with some solder when beginning. Also, when starting the solder process make sure to set the environment for efficient work, like placing the solder close by in an arrangement to quickly grab a new piece, wet the sponge to always keep the tip clean during larger projects. Here is a good cartoon from the public domain to describe in a quick pictorial way the method to make a good solder joint, enjoy!

SOLDERING IS EASY

HERE'S HOW TO DO IT

