APPLICATION NOTE

The Lake Shore Model 240 Cryogenic Sensor Input Module: Long Sensor Cable Considerations

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Introduction

Large-scale facilities that require cryogenic temperature monitoring have traditionally required measurement electronics to be placed in close proximity to the temperature sensors due to the very small signals used to perform the measurements. This can be troublesome for applications where high radiation doses can be expected in the vicinity around the sensor, or if the sensors are separated by large distances. This is a very common occurrence for high-energy physics machines such as particle accelerators.

Solution

Lake Shore 240 Series input modules have been designed and tested to allow much longer cable runs between the sensor and measurement electronics. This allows the 240 Series input modules to be placed in a consolidated location that is protected from detrimental environmental effects. With careful cable and sensor selection, the use of long cable spans becomes a viable option.

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Ideal Sensor Cable Specs

For cable lengths exceeding 10 m, cables with the following characteristics should be selected to maintain measurement reliability.

Characteristic	Value	Notes
Dielectric absorption ratio (DAR) of the conductor insulation material	<0.5%	This is a measure of how much energy can be stored in the wire insulation. This parameter has very little impact on larger signals, so this parameter is rarely specified by cable manufacturers. Polypropylene and polyethylene are recommended as they have a low DAR. PVC cable has been found to have a high DAR and is not recommended. Note that a very large DAR can reduce accuracy even on relatively short sensor cables.
Parasitic capacitance parellel to load	<35 nF	The total parallel capacitance will be approximately double the cable's conductor-to-conductor capacitance specification due to the current and voltage lines both having capacitance between their positive and negative wires.
Parasitic capacitance to shield	<60 nF	The total capacitance will be approximately double the cable's conductor-to-shield capacitance specification due to the current and voltage lines both having capacitance with the shield.

Cable Accuracy and Noise

If the conditions above are not met, measurement quality may be affected.
See the table below for details.

Sensor	Accuracy reduction	Noise increase
Cernox	Offsets of up to 12% of reading on reversing mode when DAR>10%	Noise up to 2% of reading with large vibrations
Platinum	Negligible	Negligible
Diode	Negligible	Negligible

Note: Platinum sensors are suited for temperatures above 40 K, and diode sensors cannot be exposed to magnetic fields or ionizing radiation.

Example Cable Evaluation

The following is an example of how to calculate cable performance values for a 300 m cable length.

Conductor

# Pairs	AWG	Stranding	Conductor material
2	22	7×30	Tinned copper

Insulation material: PP – Polypropylene

Electrical characteristics

# Pairs	AWG
Nominal characteristic impedance	0.095 Ω/m
Nominal inductance	0.67 µH/m
Nominal capacitance conductor to conductor	56
Nominal capacitance conductor to other conductor and shield	92

Steps

1. This cable has two twisted pairs for a total of four conductors that can be used to take four lead temperature measurements.
2. The insulating material is polypropylene, which has a very low DAR.
3. The conductor-to-conductor capacitance is 56 pF per meter. Therefore, the total parallel capacitance is:
   $2 \times 0.056 \text{ nF/m} \times 300 \text{ m} = 33.6 \text{ nF}$
   (less than 35 nF is recommended)
4. The conductor-to-shield capacitance is 92 pF per meter. Therefore, the total shield capacitance is:
   $2 \times 0.092 \text{ nF/m} \times 300 \text{ m} = 55.2 \text{ nF}$
   (less than 60 nF is recommended)

If these conditions are met, this sample cable is of a high enough quality that it can be used to take accurate measurements of sensors 300 m away.

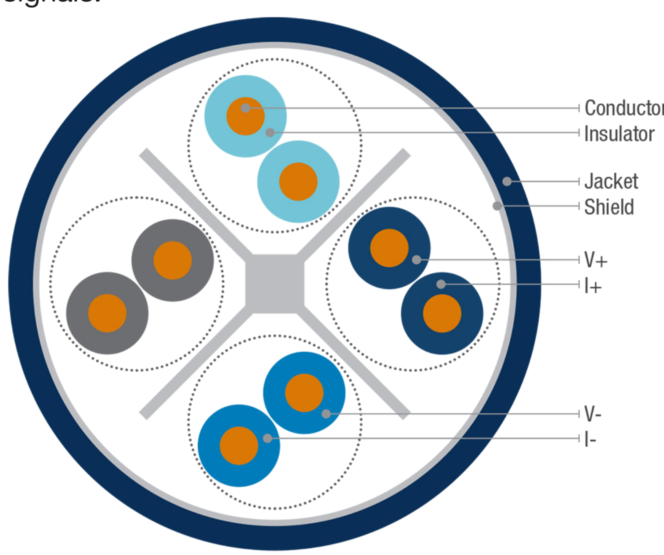
Lake Shore Validation Testing

Through extensive simulations and tests, Lake Shore has determined that the 240 Series input modules can be used to take temperature measurements over 300 m of sensor cable, albeit with slightly increased noise levels. CX-1070 sensors operating below 4 K were measured accurately using 240 Series input modules over a 300 m cable running throughout Lake Shore's test facility.

Shielded Category 6 cable with the positive and negative sensor lines on separate twisted pairs has been found to be a good choice for long-distance applications and is relatively inexpensive.

Example Category 6 Wiring Cross Section

The figure below is an example of the Category 6 wiring cross section used for testing. Note that the positive and negative lines have been separated to minimize parallel parasitic capacitance. Although only one set of I+/I-/V+/V- connections are shown, a second sensor was connected through the other twisted pairs. Also notice the outer shield, which is very important for protecting the measurement signals.



Tips for Better Performance on Long Cables: Cable Considerations

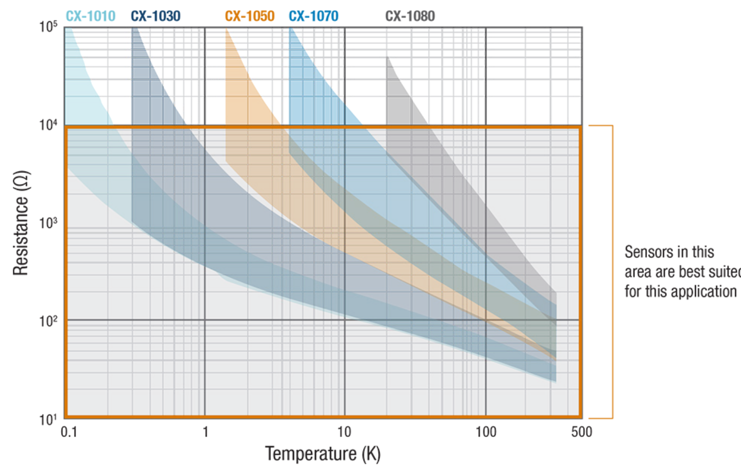
- When using twisted pair cable, connect the positive lines to one twisted pair and the negative lines to another. This reduces the parasitic capacitance parallel to the load.
- Route the cable through areas with minimal vibrations when using low excitation currents. Triboelectric effects can introduce noise up to 2% of readings at the 100 K range, and 0.5% at the 30 K range (0.2 mV and 0.05 mV, respectively). If there is no way to avoid cable vibrations, use sensor types with larger excitation currents, such as diodes and platinum RTDs, if suitable for the application.
- Cable shielding is vital. Ensure cable shielding is connected to the shield connector of one of the inputs running through the cable. To avoid issues with ground loops, it is considered best practice not to connect the shield to anything at the sensor end of the cable.

Tips for Better Performance on Long Cables: 240 Series Module Considerations

- When using the 240-8P (8-input module) for long cable runs, it is best to maintain consistency with sensor selection and measurement temperature so that sensor resistances are similar. If this is not practical, consider using 240-2P (2-input) modules for the mismatched sensors.
- Keep any unused inputs disabled.
- If the cable is introducing significant reading offsets, disabling current reversal may help resolve the issue. This will introduce thermal EMF offsets back into the measurement, but these may be less than the offset caused by the long cable run when current reversal is enabled.

Tips for Better Performance on Long Cables: Sensor Considerations

If using Cernox™ sensors, consider selecting a sensor with a lower resistance than what would be optimum for your temperature range. Selecting a sensor so that its resitance stays below 10 kΩ will result in increased electronic accuracy and resolution which should make up for the slight reduction in sensor sensitivity. As an example, select CX-1050 for applications around 4.2 K, or select CX-1030 for applications around 1.8 K.



Conclusion

Protecting measurement electronics from harmful exposure can be a challenge in high-radiation environments. With Lake Shore 240 Series input modules and careful wire and sensor selection, we have shown that it is possible to maintain measurement performance over long cable spans, allowing the electronics to be installed in protected locations.