UEI Application Notes:

Thermocouple Measurement • Using AI-225/AI-207

App Note #021
A thermocouple is a sensor used to measure temperature in a wide range of applications. Its ability to sense temperature is based on the so-called “Seebeck Effect”, discovered by Thomas Seebeck in 1821. The Seebeck Effect, also known as the thermoelectric effect, states that any electrical conductor will produce a voltage when subjected to a thermal gradient. The magnitude and polarity of the voltage produced varies with the type of metal used for the conductor and the magnitude and polarity of the thermal gradient.

A thermocouple is constructed by connecting two conductors, composed of dissimilar metals, at both ends to form two junctions. Since the second conductor senses the same thermal gradient as the first, it also produces a voltage. This voltage, however, is different from that of the first conductor because it is made from a different metal. The small difference between the two voltages, which is typically in the millivolt range, is used for measurement of the thermal gradient.

Since the voltage is generated by a thermal difference between the junctions, one junction is called the “hot junction” and the other is called the “cold junction” or “reference junction.” An increase in the temperature difference between hot and cold junctions increases the voltage generated in a non-linear relation. The degree of linearity is a property of the two metals used to make the thermocouple.

Breaking the circuit to insert a voltmeter as shown in the diagram below illustrates how a thermocouple is typically used to measure temperature in an application.

**Cold Junction Compensation Theory**

Typically, a voltage is produced by a thermocouple at any given temperature. For example, the K-type thermocouple at 300°C will produce 12.2mV. To measure this voltage accurately, we must compensate for using any contact made to a thermocouple -- a technique called cold junction compensation (CJC). In case you...
are wondering why connecting a voltmeter to a thermocouple does not make several additional thermocouple junctions (leads connecting to the thermocouple, leads to the meter, inside the meter etc), the law of intermediate metals states that a third metal, inserted between the two dissimilar metals of a thermocouple junction will have no effect provided that the two junctions are at the same temperature. It is important to keep this in mind when we construct thermocouple junctions.

Based on this law, it is quite acceptable to make a thermocouple junction by soldering the two metals together as the solder will not affect the reading. In practice, however, thermocouple junctions are made by welding the two metals together (usually by capacitive discharge) because this ensures that the performance is not limited by the melting point of solder.

**Cold Junction Compensation Using a PowerDNA Screw Terminal Panel (STP)**

Ambient temperature measurement is done by Cold Junction compensation (CJC). A PowerDNA Screw Terminal Panel has an isothermal metal block which is at ambient temperature. The voltage generated by the ambient temperature is measured using a dedicated CJC channel available in UEI Analog Input Layers. Software then determines the voltage created at the “cold” junction and subtracts this error voltage before linearizing the thermocouple input.

Table-1 describes the CJC channel number for various Analog Input Layers using a DNA-STP-AI-U or a DNA-AI-207TC Screw Terminal Panel. Note, however, that the STP-AI-207TC is not used with the AI-225 Layer.

<table>
<thead>
<tr>
<th>Layer</th>
<th>CJC channel Number</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>AI-207</td>
<td>Channel 33</td>
<td>Single-Ended</td>
</tr>
<tr>
<td>AI-225</td>
<td>Channel 24</td>
<td>Single-Ended</td>
</tr>
</tbody>
</table>

**Table-1**

**Hardware Setup of Analog Input AI-225 and AI-207 Layers**

Analog Input AI-225 and AI-207 Layers have a dedicated CJC channel which measures voltage corresponding to the ambient temperature. The example below shows the hardware set to...
measure temperatures accurately using a thermocouple. The thermocouple input is connected to the one of the Analog Input channels and the CJC input is configured in software as per Table-1.

Within the “usable” temperature range of any thermocouple, there is a proportional relationship between thermocouple voltage and temperature. This relationship, however, is by no means a linear relationship. In fact, most thermocouples are extremely non-linear over their operating ranges. To obtain temperature data from a thermocouple, it is necessary to convert the non-linear thermocouple voltage to temperature units. This process is called “linearization.”

Several methods are commonly used to linearize thermocouples. At the low-cost end of the solution spectrum, one can restrict the thermocouple operating range such that the thermocouple is nearly linear to within the measurement resolution. At the opposite end of the spectrum, special thermocouple interface components (integrated circuits or modules) are available to perform both linearization and reference junction compensation in the analog domain. In general, neither of these methods is well-suited for cost-effective, multipoint data acquisition systems. In addition to linearizing thermocouples in the analog domain, it is possible to perform such linearizations in the digital domain. This is accomplished by means of either piece-wise linear approximations (using look-up tables) or arithmetic approximations, or in some cases, a hybrid of these two methods.
Thermocouple Measurement-Using AI-225/AI-207:

**Software Implementation**
To do accurate temperature measurements, one has to read the channel where the thermocouple is connected, as well as a CJC channel. Feed these values to a NIST-derived polynomial formula to get an accurate thermocouple junction temperature.

**Code Snippet for the AI-225:**
To read the CJC channel, you must specify Channel 24 in single-ended mode in the channel list.

The snippet of the code is shown below:

```c
for (i = 0; i < CHANNELS; i++) {
    cl[i] = i | DQ_LNCL_GAIN(DQ_AI225_GAIN_1) | DQ_LNCL_DIFF;
}
c1[CHANNELS] = 24 | DQ_LNCL_GAIN(DQ_AI225_GAIN_1);
```

**Code Snippet for the AI-207:**
To read the CJC channel, you must specify Channel 33 in single-ended mode in the channel list.

The snippet of the code is shown below:

```c
for (i = 0; i < CHANNELS; i++) {
    cl[i] = i | DQ_LNCL_GAIN(DQ_AI207_GAIN_1) | DQ_LNCL_DIFF;
}
c1[CHANNELS] = 33 | DQ_LNCL_GAIN(DQ_AI207_GAIN_1);
```

**Open TC Detection:**
A DNA-STP-AI-U Screw Terminal Panel has the hardware implementation to detect an open TC. An Open TC will show high positive temperatures beyond the limits of the thermocouple range.

**References:**
- DNA-AI-225 User Manual
- DNA-AI-207 User Manual
- DNA-STP-AI-U User Manual
About UEI:

Founded in 1990, UEI is a leader in the computer based data acquisition and control industry. Serving customers world-wide, UEI products based upon PCI, PXI, ISA and Ethernet interfaces offer unequaled performance as well as flexibility. We are committed to providing the highest quality hardware, software and services, enabling engineers and scientists to interface data-acquisition and control hardware to the real world. Through our state-of-the-art technologies we serve the needs of individual researchers and developers as well as OEMs.