Bruce Trump *Jun 26, 2012*

Perhaps you've never used a thermocouple and think you have no reason to know how they work. I disagree. I believe that ten minutes of reading will be well spent. If you already know this much, please read and tell me if I got anything wrong.

Thermocouples are temperature measurement sensors made from at two different metals. They might be elements such as copper or iron or alloys made from a specific mixture of metals. Two wires of different metals join at a *junction*, bringing us to a first important point—n**o voltage is generated at the junction**. Just like any two wires you might connect, there is no voltage created at the connection.

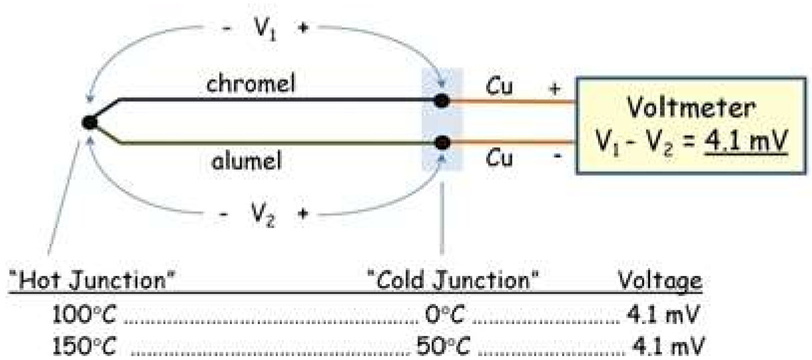

Figure 1. K-type thermocouple (chromel-alumel), ≈ 41 µV/°C

Now, get this: When one end of a conductor is a different temperature than the other, a voltage is generated across the wire. Yes… believe it! This voltage is present without current flowing and regardless of the resistance of the wires—it's the Seebeck effect. If two different metals are used they generate two different voltages and the *difference* between the two can be measured at the open-circuit end, figure1. Note that if you try to measure the absolute Seebeck voltage of a single wire with the same metal, your measurement wire generates the same voltage and you measure zero. You can only measure the difference between dissimilar pairs.

In making this measurement, you create one or two more junctions at the measurement end (two if neither of the wires is copper). These are called *cold junctions* because, generally (but not always), the measurements made at the other end are warmer.

Thermocouples measure a *temperature difference*. Note that in figure 1, you measure the same voltage in both example cases. A 100°C temperature *difference* between hot and cold junctions generates 4.1mV. The old-fashioned way to get an *absolute* temperature measurement of the hot end was to immerse the cold junctions in an ice bath (another reason it's called a cold junction). Published thermocouple tables assume that the cold junction(s) are at 0°C.

If you want to know the absolute temperature of the hot junction but don't want to use an ice bath, you must know the temperature of the cold junction(s). This can be measurement can be made with a semiconductor sensor such as TMP20 or ADS1118 (combined with A/D converter), thermistor, RTD or some other sensor capable of absolute, not relative measurement. A voltage equal to the thermocouple coefficient is summed in, according to the measured cold junction temperature, figure 2. This can be done in analog or digitally and is called *cold junction compensation*. The result of this sum is the same voltage that would be generated if the cold junction were at 0°C.

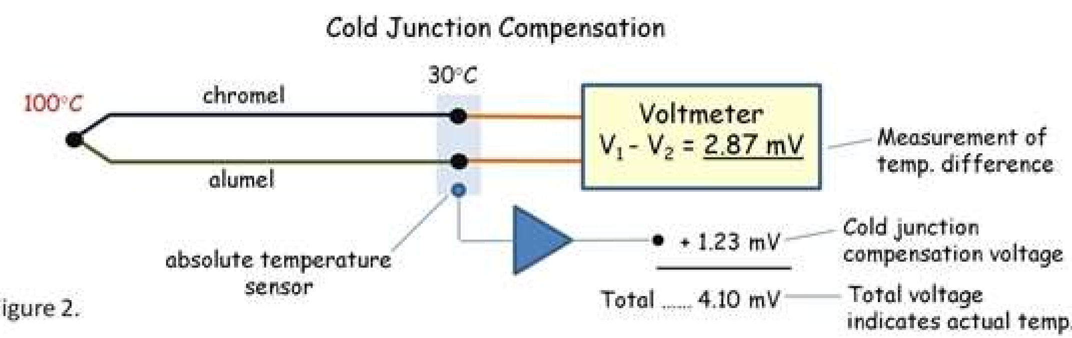

Figure 2.

So if you need an absolute temperature sensor for the cold junction, why not just use that sensor to measure the hot end? Thermocouples can measure over a much wider temperature range, from cryogenic temperatures up to 1800°C or more, depending on the type. There may be other advantages, depending on the application.

If all wires generate these voltages, why don't we see the effects in our circuits more often? Well, at the normal temperatures of our electronics the voltages are pretty small and we generally use the same or very similar conductors with relatively low Seebeck coefficients. When we use different metals, the two junctions are often near the same temperature.

- If you are measuring tiny DC voltages, you need to be very careful. For example, when we measure the offset voltage of precision chopper op amps we must select our components and materials such as connectors and wiring carefully. Mechanical layouts must assure that junctions of differing conductors are near one another and thermally coupled. We use latching relays to minimize heating and keep other heat sources far from low-level circuitry. It's tricky business to accurately measure a few microvolts and unwanted thermocouples are often the ultimate limitation to accuracy.

There's more to know, of course, and much more information available on the internet but these are the 10-minute basics.

Now… thermocouple experts out there… did I get anything wrong or miss something really important? Corrections or comments welcome.

Bruce

6 comments   0 members are here

Ed Barney *over 12 years ago*

I want to point out that there are specific types of thermocouples, based on the two metals used. Your example uses type "K" (chromel-alumel), there are others including types "T", J", "E", "N", which are generally selected for the temperature range. ANSI/ASTM E-230 and MC 96.1 and IEC 584-3 specify different (non-harmonized) color codes for thermocouple wire and connectors.

Bruce Trump *over 12 years ago*

Thanks, Ed. Yes, there are many other thermocouple types and I am no expert on their selection. One of the factors can be the sensitivity of the metals to the surrounding environment--corrosion, etc.

Regards, Bruce.

Stephen Power *over 12 years ago*

Hi Bruce. For precision temperature measurements it is critical that the voltmeter has very low input bias current. The resistance of the thermocouple depends naturally on length but also on both type and temperature and the ratio of the resistance in the 2 individual thermocouple wires may be as high as 25:1. 100 feet of 30AWG type K has a resistance of ~600ohms (by my rough calculations) so if the input offset current was 50nA the voltage error is ~30uV. Type K sensitivity is ~40uV/degC (it varies with temperature as well) so this equates to ~0.75degC.

Another point I would make is that accuracy also depends directly upon the accuracy of the CJC. If the CJC sensor accuracy is only 1degC then you can't get better measurement accuracy than this.

Jayant Deshpande *over 12 years ago*

In most cases, the cold junction is located quite some distance away from the hot junction. These long wires pick up noise and introduce errors. Shielding and filtering are important and need special attention while making accurate thermocouple measurements.

Regards,

Jayant

Brad Nelson1 *over 12 years ago*

I'm not an expert, but maybe someone can provide pointers on the design considerations and advantages of grounded thermocouples? How does this change the input circuitry between the two probe leads? And are there any ground loop issues with having a long grounded thermocouple probe cable attached to, say, a vehicular chassis ground at a distance when the sensing circuitry is also grounded to the chassis?

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