THERMOELEME

Easy processing with the MAX6675

Design engineers like to use thermoelements when it comes to probing around in really wide temperature ranges. Modern integrated circuits are available that act as sensor interfaces to a microcontroller.

The operation of thermoelements is based on the Seebeck effect: a temperature difference across a wire causes movement of free electrons. The amount of charge displacement is dependent on the electrical properties of the wire.
As illustrated in **Figure 1**, thermal energy is applied to electrons normally moving inside a crystal grid structure. The applied energy causes the electrons to move faster and eventually diffuse from the hot to the cold end. There they slow down again, releasing their energy. As electrons concentrate at the cold end, a negative electrode is formed relative to the hot end. At the same time an electrical field is established maintaining a dynamic balance between the electrons.
If the voltage between the hot and the cold end is to be measured, one thing you have to do is connect the hot end to an electrical conductor that's also exposed to the temperature changes. If this second conductor has the same electrical properties as the first one, then no voltage can be measured between the charge density points. However if two different conductors are used, a voltage exists between the two 'cold' ends that's dependent on the temperature difference and the electrical properties of both conductors.
In the test arrangement shown in **Figure 2**, no absolute thermovoltage can be measured, only differential levels. In order to establish the temperature at the measurement point, the temperature at the connection terminal has to be known as well as constant. Datasheet values like 'thermovoltage at 200 °C' always relate to a comparison to the thermovoltage at 0 °C.
If the end of the thermoelement is at an unknown temperature (and far removed from the measurement electronics) it has to be extended right into the area of known temperature (comparison point), using a special compensating conductor. A problem arises with the measurement of thermovoltage using an instrument whose connection terminals are made of a different material. These create two additional thermoelements, which may be compensated, though, either by keeping the comparison point at a known temperature, or perform an appropriate correction at the instrument terminals.

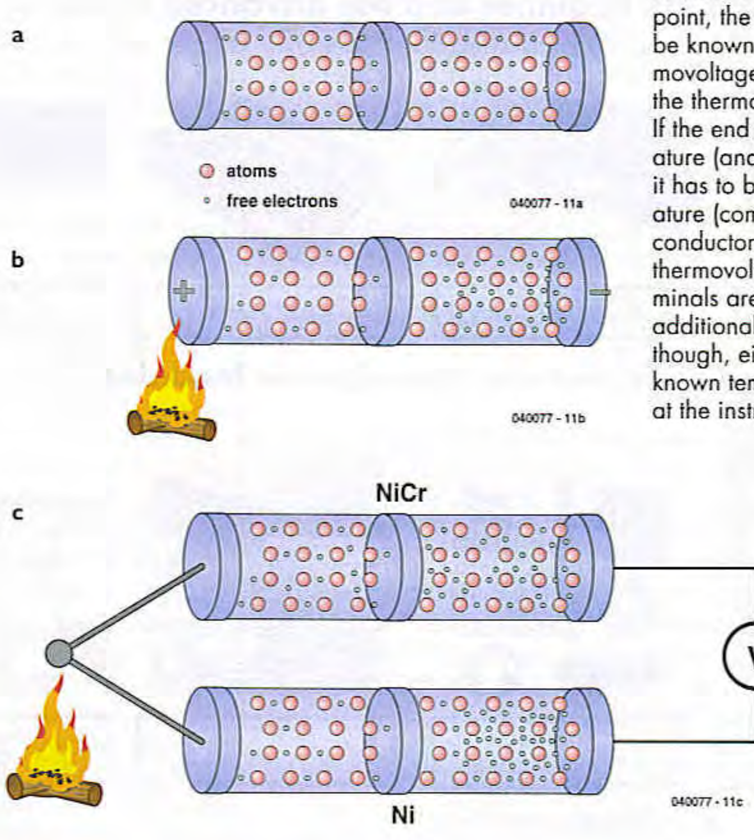

Figure 1. In a conductor, valence electrons are equally distributed (a), but diffuse to the cold side when the conductor is heated at one side (b). If two conductors of different material are connected at the hot sides, the free electrons cause a voltage difference by concentrating at the cold side.

NTS

Thermoelements

The voltage caused by the thermoelectric effect is very small at just a few millivolts per Kelvin, depending on the metal or alloy combination. As a result, thermoelements are not used for measurements in the range –30 °C to +50 °C because the temperature difference with the reference is simply too small to ensure a reliable signal. Consequently thermoelements are typically used for measurements up to 1000 °C.
From the multitude of metal and alloy combinations, a few have been selected and their voltage series laid down in DIN standard EN 60584 (types L and U are obsolete and now replaced by J and T). The element types differ in respect of maximum temperature and their characteristics as shown in **Figure 3**. The maximum temperature is the highest value at which the tolerance is maintained. Under 'defined up to' you find the highest temperature at which the thermovoltage complies with the standard. With the thermocouples listed, the first material is always the positive terminal.
As you can see from the response curves, the voltage supplied by thermoelements is not a perfectly linear function of applied temperature. If you want really accurate readings, then a linearisation circuit is required specifically designed for each type of element. **Figure 4** shows that for a K element the maximum deviation from the linear function is no more than 0.5 K a 750 °C. If you can live with such a small error in a relatively narrow measurement range, then a complex linearisation circuit is not in order.

Processing the values

In a previous publication from our archive, 'Fast, Precise Thermometer' (*Elektor Electronics* January 1992), we already proposed a thermoelement application. In that circuit, the comparison point compensation was handled by discrete components. Today, the semiconductor industry supplies complete, dedicated converters in a chip. An example is the MAX6675, a 12-bit A/D converter with SPI interface (and complementary control) and a noise-suppressing, buffered differential measurement amplifier in front of it (not shown). The internal diagram (**Figure 4**) also reveals a compensation diode that captures the temperature at the comparison point and so provides the necessary correction of the measured value.
The MAX6675 is ready for measurement point temperatures from 0 °C to 1023.75 °C and is capable of compensating comparison point temperatures of –20 to +85 °C. This results in an impressive resolution of 0.25 °C. By comparison, another IC from the series, the MAX7774 with 10-bit resolution achieves a resolution of 1 °C.

SPI

The 'cleaned' measurement value is finally digitized by the A/D converter, serialized, and may be requested by a microcontroller (read-only). The extremely simple SPI protocol supplies a 16-bit word in response to a clock signal. Not much needs to be said about the timing, as lots of literature on the protocol is available from Internet. **Figure 5** shows the structure of the 16-bit word. A sequence of zeroes at positions 3 (LSB) through 14 (MSB) means a temperature of 0 °C, while twelve ones indicate 1023.75 °C which is just another rather uncomfortable level.

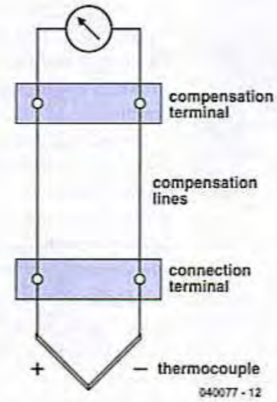

Figure 2. Structure of a thermoelement with a hot measurement junction and a cold comparison junction. A compensation wire allows the comparison point to be remote from the connection point.

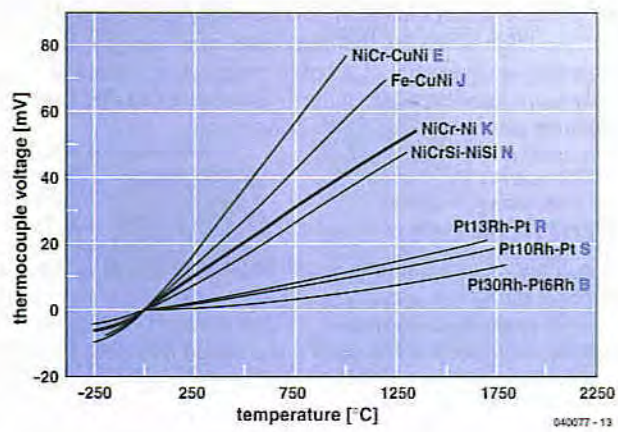

Figure 3. Thermovoltages from a number of standardised metal and alloy combinations.

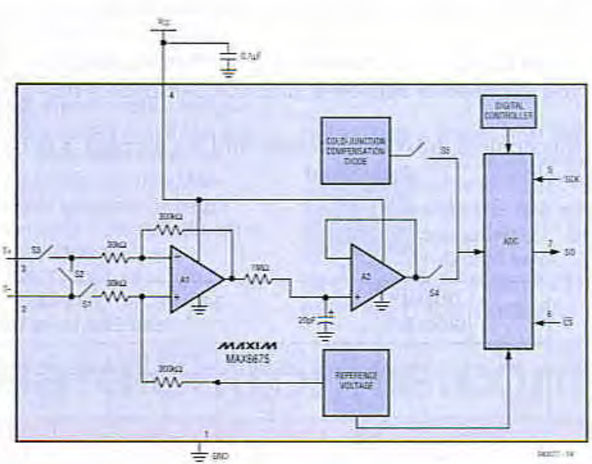

Figure 4. Internal diagram of the MAX6675.

Thomas Johann Seebeck

Thomas Johann Seebeck was born on April 9, 1770, in Reval, now Talinn, the capital of Estonia, into a wealthy merchant family. His father being of German origin, medical science studies at the Universities of Berlin and Göttingen were more or less imposed on young Thomas Johann. In 1802 he graduated as a medical doctor and although he did set up practice in Göttingen, Seebeck decided to change to physics research, hence he is known from his experiments in physics rather than his achievements as a general practitioner. Mostly self-educated and a 'freeman student' he went to Jena, Bayreuth and Nürnberg where he deepened his knowledge of physics. He met Johann Wolfgang von Goethe and joined him in his work on the (anti-Newtonian) theory of colour and coloured light.

Seebeck investigated the heating effect of different colours in the solar light spectrum. In 1808, he was the first to produce potassium-amalgam and in 1810 he noticed the colour susceptibility of moist silver oxide (a precursor to colour photography). In the same year, Seebeck observed the magnetic properties of nickel and cobalt. A few years later, in 1818, he discovered the optical activity (rotation of the polarized area) of sugar solutions. He then returned to the University of Berlin where he researched electrical magnetization of iron and steel. In 1821

Seebeck discovered the thermoelectriceffect and two years later proposed a thermoelectric voltage series as well as published the fruits of his research in 'Magnetic Polarization of Metals and Ores by Temperature Difference. Proceedings of the Prussian Academy of Sciences'. Seebeck continued to work at the Berlin Academy for 13 years. He died in Berlin on 10 December 1831.

Element	Max. temperature	Defined up to	Positive terminal
J: Fe-CuNi	750 °C	1,200 °C	black
T: Cu-CuNi	350 °C	400 °C	brown
K: NiCr-Ni	1,200 °C	1,370 °C	green
E: NiCr-CuNi	900 °C	1,000 °C	violet
N: NiCrSi-NiSi	1,200 °C	1,300 °C	lilac
S: Pt10Rh-Pt	1,600 °C	1,540 °C	orange
R: Pt13Rh-Pt	1,600 °C	1,760 °C	orange
B: Pt30Rh-Pt6Rh	1,700 °C	1,820 °C	–

Bit 2 has a special function. It is normally low, but will carry a High when the thermocouple input is open, for example, as the result of a cable malfunction. This will only work, however, when the T– input is grounded (as close as possible to the GND connection).

Practical use

A number of requirements should be fulfilled in order to achieve maximum accuracy.

- Self-heating of the MAX6675 should be avoided. Provide for sufficient ventilation and large ground planes.
- The thicker the wire used for the thermoelement and the compensation line, the smaller the risk of measured values being corrupted by the wire resistance(s).
- If you cannot avoid the use of a thin thermoelement, you still need to employ a thick compensation wire.
- Mechanical stress on the cable and the element is to be avoided.
- Twisted-pair cable should be used with long thermoelement connections.
- Sudden temperature changes are to be avoided.
- Users should always observe the maximum temperature specified for the thermoelement, as well as the much lower value for the compensation line.
- The mechanical loading of the element is to be matched to the application.
- Despite the use of a low-noise measurement amplifier inside the MAX6675, the thermoelement, all wires and connections should be kept far removed from of electrical noise sources.

(040077-1)

For further reading

MAX6675 datasheet
http://pdfserv.maxim-ic.com/en/ds/MAX6675.pdf

http://en.wikipedia.org/wiki/T._J._Seebeck

BIT	DUMMY SIGN BIT	12-BIT TEMPERATURE READING												THERMOCOUPLE INPUT	DEVICE ID	STATE
Bit	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
	0	MSB											LSB		0	Three-state

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Figure 5. Structure of the 16-bit word supplied by the MAX6675.