IEEE 1451.4 Standard Working Group
Telephone Meeting, Dec 21, 2000
Meeting Minutes, issued 12-21-00, approved 08-23-01

Chair: T. Licht
Secretary: P. Hufnagel

Attendance:
Mike Dillon, Modal Shop, mdillon@modalshop.com
Mike Dunbar, Crossbow, mdunbar@xbow.com
Garritt Foote, National Instruments,garritt.foote@ni.com
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Stan Woods, Agilent, stan_woods@agilent.com

1) T-Block: Carlos Lopez-Reyna
   a) Comments on T-Block development tools not yet available.
   b) The DL has no provision for an "IF" statement, which should be added.
   c) Both DL and UML may be used to describe a template. Examples of various templates, in use, are needed as tutorial material for the standard, and to validate the T-Block.
   d) Communication from G. Foote, Generic Transducer TEDS Template Description:

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Generic information for popular transducers

A generic template 1451.4 that would support the majority of transducers in popular use should be feasible. Since not every transducer type in the world need be addressed, limitations of minority transducers are acceptable. This document is intended to detail the information necessary in the TEDs of a transducer using such a generic template. This document should be used as a guide in creating such a template.

A generic template should allow for the following sets of information:

1. Universal information. All transducers should allow for information such as the manufacturer, model number and version, serial number, others?
2. A description of the physical phenomena sensed or controlled by the transducer and a description of the electrical interface provided by the transducer, as well as a mapping function for translating between the two. This information is used by the measurement/control system for interpreting between real-world signals and the measured/controlled electrical signals.
3. A description of the signal conditioning requirements of the transducer. This should provide enough information about the electrical interface to allow a measurement/control system to provide plug-and-play configuration of signal conditioning settings such as gain, excitation levels, and filtering.
4. Calibration information for the transducer. At a minimum calibration date, period, and initials should be defined. I also think that actual calibration information should be provided for. Perhaps this can be done by modification to the mapping functions of the second section, but I think a section of additional calibration information, with a structure similar to that of the mapping method description is more reasonable.

So far, this document has a draft set of ideas for the second of these sections, which I think is the most critical. I've left a number of comments and invitations for feedback throughout the document in italics. I believe that the first section should be quite straightforward and patterned after the existing work for accelerometers. The third section will likely follow in the same pattern as the second, but the fourth section may take a more planning. A better understanding of how calibration is to be handled with the existing accelerometer templates would be beneficial to me.

-Garritt Foote

*National Instruments*Scaling Information:
Electrical signal range:

***Minimum electrical value**: (4-byte float)*

- **Maximum electrical value**: (4-byte float)
- **Electrical Units name**: (string)

Physical signal range:

- **Minimum physical value**: (4-byte float)
- **Maximum physical value**: (4-byte float)
- **Physical Units name**: (string)

Maping Method: (Enumerated list)

0. Linear (mx+b)
1. Inverse ($m[x+b]^{-1}$)
2. Inverse ($mx^{-1} + b$)
3. Thermocouple (NIST curves)
4. Thermistor (Steinhart-Hart equation)
5. RTD (Industry standards or Callendar-VanDusen)
6. Strain gauge (Bridge equations)
7. Arbitrary- 1451.2 method

Thermocouple specifics (if mapping method = 2):

- **Thermocouple Type**: (Enumerated List of NIST types)
  0. J
  1. K
  2. R
  3. S
  4. N
  5. T
  6. E
  7. B
- **Cold Junction source**: (Enumerated List)
  0. None
  1. Internally compensated (0 °C)
  2. Cold Junction Channel
     - **Cold Junction Channel**: (channel number)

Thermistor specifics (if mapping method = 3):

- Steinhart coefficients: (4-byte floats)
  - **Steinhart A**
  - **Steinhart B**
  - **Steinhart C**

RTD specifics (if mapping method = 4):

- **RTD curve**: (Enumerated List)
  0. Pt100, $\alpha = 0.003750$
  1. Pt100, $\alpha = 0.00385055$
  2. Pt100, $\alpha = 0.003902$
  3. Pt100, $\alpha = 0.003911$
  4. Pt100, $\alpha = 0.003920$
  5. Pt100, $\alpha = 0.003926$

6. Pt1000, $\alpha = 0.003750$
7. Pt1000, $\alpha = 0.00385055$
8. Pt1000, $\alpha = 0.003902$
9. Pt1000, $\alpha = 0.003911$
10. Pt1000, $\alpha = 0.003920$
11. Pt1000, $\alpha = 0.003926$
12. Ni (need to list the standard Nickel RTD types)
13. Cu (need to list the standard copper RTD types)
14. Custom
    Custom RTD Callendar-Van Dusen coefficients: (4-byte Floats)
    - **R_0**
    - **A**
    - **B**
    - **C**

Strain Gauge Specifics (if mapping method = 5):

Bridge type: (Enumerated list)

0. Half Bridge, one element
1. Full Bridge, two elements
2. Full Bridge, opposite elements
3. Full Bridge, four elements

Gauge Factor: (binary)

0. GF = 2 (ideal metal)
1. non-ideal GF
   Non-ideal GF: (4-byte Float)

Poisson's Strain: (binary)

0. $\nu = 0$ (ideal: no transverse strain)
1. non-ideal ν
   Non-ideal n: (4-byte Float)

Description of Fields (Actual fields listed above in **Bold**):

Electrical signal range:

This is the range of electrical signal between the transducer and the measurement/control device. This will usually be a voltage, current, resistance, frequency, or ratio of voltages. The **minimum electrical value** and **maximum electrical value** values indicate the defined limits of the transducer. **Electrical units** is a string name of the units that the **minimum electrical value** and **maximum electrical value** are in. It will usually be something like "V", "mV", "mA", "Ohm", "Hz", or "mV/V"

Physical signal range:

This is the range of the physical phenomena being measured or controlled by the transducer. It could be a pressure, temperature, strain, flow, distance, acceleration, frequency, etc. The **minimum physical value** and the **maximum physical value** are the physical values that correspond to the electrical range values. **Physical units** is a string name of the units that the **minimum physical value** and **maximum physical value** are in. It could be things like "psig", "psia", "°C", "°F", "K", "microstrain", "gpm", "mph", "ft", "g", "m/s^2", "Hz", etc.

My Note on Units: We could, as discussed at the face-to-face meeting in Gaithersburg, use Hewlett-Packard's proposal for dimensions that was adopted by 1451.2. This has real merit in being easily machine readable for use by software that makes use of units by being aware of the dimensions of a number. National Instrument's LabVIEW environment, for example, can be aware of the dimensions of a value throughout it's use and combination with other values. When it is time to display any value, the user can choose the units to display the value in (such as mm, m, ft, in, etc.). However, our experience has been that in practical use few of our customers use the feature of dimensioned values, preferring instead to treat all their numbers as dimensionless values while just "knowing" what the units are. As a result, these users tend to have a great affinity for have ranges and values displayed and scaled to the "right" units. For example, displaying a range of 0.004 to 0.020 Amps is much less preferable to displaying a range of 4 to 20 mA. Of course, software products could allow the user to choose the range of data, but if the range of data is usually in “wrong” units, then the plug-and-play aspect is much diminished since the user must always go through this configuration step. The 1451.2 method will, unfortunately, most often provide the “wrong” units. For example, current will always be in amps (not milliamps); pressure in Pascal (which is kg/(ms^2)) instead of psi, psia, psig, mmHg; strain will always be in meter/meter (instead of microstrain); and so on. My suggestion is that since sensor manufacturers will most likely know what the “right” units are for a given customer, and that since the units are most often to be used simply as a display for a customer to look at in order to “know” the units of his values, the sensor manufacturer should be given the ability to choose the string to display and the units which correspond to the minimum and maximum ranges.

Mapping Method:

Now that the physical units and the electrical units are known, the conversion between these units is needed. The value **Mapping Method** is an enumerated list intended to handle the majority of sensor types in common use. Based on the **Mapping Method** selected, it may be that more information specific to that method follows. The methods that should handle the majority of sensor cases are:

Linear mapping method: Of course, this will be a very common selection for many transducers. The minimum physical value is corresponds to the minimum electrical value, and the maximum physical value corresponds to the maximum electrical value, with a linear mapping between these two pairs of data points. I would expect that most 4-20 mA and 0-10 V conditioned transducers would use the linear mapping method. No other mapping information specific to this method is needed.

Inverse ($m[x+b]^{-1}$) mapping method: Not nearly as popular as linear, but still common enough to be worth using. In this case, the minimum and maximum electrical and physical values define the two endpoints of the equation (Physical Value)= m × [(Electrical Value) + b]$^{-1}$. An example would be sensors that output a frequency proportional to the physical value, where the electrical value is in units of time (for period measurements). Since the two endpoints are sufficient to define the mapping, no additional information specific to this method is needed.

Inverse ($mx^{-1} + b$) mapping method: Another inverse relationship similar to the previous one, except that the offset is applied to the physical value, rather than the electrical value, so that the relationship becomes (Physical Value) = b + m × (Electrical Value)$^{-1}$. An example would be a position sensor with a voltage-excited potentiometer in series with a fixed resistor that had physical units of position and electrical units of voltage. Since the two endpoints are sufficient to define the mapping, no additional information specific to this method is needed.

Thermocouple mapping method: Thermocouples have complex but well defined mappings between electrical values (dimensions of voltage) and physical values (dimensions of temperature). If a thermocouple mapping is chosen, additional fields are required to further define the mapping.

Thermocouple Type: If the thermocouple mapping method is chosen, the next field will indicate which of the 8 NIST defined thermocouple mapping methods are used. Although there are a few other proprietary thermocouple standards in use, they are (1) rare enough not to warrant concern about inclusion in this default, generic template and (2) complex enough to be best handled by the arbitrary mapping method described later. Certainly they could also have their own enumerations in this standard, and if any thermocouple manufacturer petitioned to have their type included I think we should do it, but I don’t recommend searching out these non-standards.

Cold Junction Source: To convert between temperature and voltage, and cold junction temperature is also needed. If the sensor provide thermocouple wires to the measurement device, than it would be the responsibility of that device to measure the temperature of its cold junction and the sensor would have a value of “none” for this field. There are also temperature sensors which are linearized (actually, non-linearized) to mimic the behavior of a thermocouple with a cold junction temperature of 0 °C. These sensors would have a value of “internally compensated (0 °C)”, as would sensors that provided for an ice bath cold junction. Finally, it may be that some sensors would provide non-thermocouple wires to the measurement device, with their own cold junction and associated cold-junction temperature sensor included. This would necessarily be a multi-channel sensor, and the value of this field would indicate that the sensor has its own “cold junction channel”. This field would then be followed by another **Cold Junction Channel** field, which would point to some channel with physical units of temperature to be used in measuring the cold junction. *I would like to point out that unless we have a clear method for describing multi-channel sensors, it might be best to not allow for the option of a sensor with its own cold junction channel.*

Thermistor mapping method: Thermistors, at least the negative temperature coefficient ones popular for temperature sensing, have a mapping between temperature and resistance that follows an equation known as the Steinhart-Hart model. This is the standard model adopted by all sensor manufacturers. *(The positive temperature coefficient thermistors that are used for sensor applications are generally designed to have a linear temperature/resistance relationship that would be handled by the linear mapping method. This an example that points out the difference between a mapping method and a transducer type.)* The Steinhart-Hart equation uses a set of three coefficients, known as the **Steinhart coefficients A, B,** and **C**. The coefficients follow the equation

$$1/T = A + B \ln(R) + C \ln(R)^3$$

where T= temperature and R = resistance in Ohms. If this mapping method is used, each of these three coefficients should follow in the TEDS as 4-byte floating point numbers. *I think this might be an example of an equation which would actually not work well with the standard 1451.2 piecewise polynomial method. I'm not sure that you can take the log of a value before using it in the polynomial.*

There are a number of reasonably standard sets of Steinhart coefficients in use among thermistor manufacturers, but it is a very large number since there is a set of coefficients for each nominal resistance and for each material type. We could enumerate a long list of the most common values, and leave the use of coefficients as a last, "custom" selection as I do for RTDs.

RTD mapping method: RTDs (resistive temperature devices) are sensors that convert a physical measurement of temperature to an electrical value of resistance. The mapping between temperature and resistance of popular RTDs follow one of a few standard curves. If a mapping function of RTD is chosen, then the next field in the TEDS describe which of the standard **RTD Curves** is used to map resistance to temperature for the sensor. The standard method of describing different RTD curves is to define the RTD material (Platinum, Nickel, or Copper), the 0 °C resistance (R_0), and an "alpha" value (α x R_0 is the average change in resistance per degree C of the RTD between 0 and 100 °C). There is a small enough range of standard RTD material, R_0, and α values that they can be listed in an enumeration. However, we can also allow for other non-standard RTD types with the use of a "custom" choice of RTD. The most popular model of an RTD's curve is the Callendar-Van Dusen equation, which uses the four **Callendar-Van Dusen Coefficients R_0, A, B, and C** that fit the equation:

For $T < 0$ °C $\quad R = R_0 \times (1 + A \times T + B \times T^2 + (T - 100\ °C) \times C \times T^3)$

For $T > 0$ °C $\quad R = R_0 \times (1 + A \times T + B \times T^2)$

Where T = temperature in °C and R equals resistance

If the "custom" setting is chosen for the RTD curve paramter, the next four fields will be the Callendar-Van Dusen coefficients expressed as 4-byte floats.

Strain Gauge mapping method: A single strain gauge element is a resistance which has a linear mapping between physical units of strain (usually microstrain, $\mu\varepsilon$, which is a dimensionless quantity meant to be a ration of distances: $1\ \mu\varepsilon = 1\ \mu$m/m) and electrical units of resistance. However, in practice a strain element is used in a bridge circuit with other resistors or strain elements. This bridge circuit is excited with a known voltage and a differential voltage is read back from it. The electrical units in a bridge element would typically be mV/V. In many cases, a linear approximation is still good enough to convert between the mV/V electrical value and the $\mu\varepsilon$ physical strain. However, depending on the application of strain elements and other resistors, the conversion is best described with one of a few non-linear equations. The bridge circuit consists of a total of 4 resistors, each of which could be a strain element, a "transverse" or "compensating" strain element, or a dummy fixed resistor. The compensating strain elements have a resistance that changes with the *Poisson Strain*, which is a strain in the transverse orientation to the measured strain. The ratio of the Poisson strain to the measured strain is called the Poisson Ratio, ν. The mapping equations also take into account the *Gauge Factor* (GF) of the strain elements, which is the ratio of the percentage change in resistance for a percentage change in length of the strain gauge. The ideal GF of a metal strain gauge is 2. If a Strain Gauge mapping method is chosen, the next fields in the TEDS describe the bridge circuit, Gauge Factor, and Poisson Ratio.

Bridge Type: There are four basic bridge types in common use. By setting the Poisson Ratio of these types to 0 you can get other derived circuits, but four main types are as follows:

where ε = strain, $V_r = V_m/V_{ex}$, GF = Gauge Factor, ν = Poisson's ratio

Gauge Factor: If the gauge factor is 2 (ideal metal) this field is a zero. If this field is a one, the next field is a 4-byte float giving the **Non-ideal GF**.

Poisson's Ratio: If the Poisson's ratio is 0 (no transverse strain), this field is zero. If this field is a one, the next field is a 4-byte float giving the **Non-ideal n**.

Unfortunately, the material to which the strain gauge is mounted determines Poisson's ratio, and both Poisson's ratio and the Gauge Factor can be affected by the mounting of the strain gauge. This means that the mapping of strain to mV/V cannot be adequately expressed in a TEDs of a strain gauge independent of the material to which the gauge is ultimately mounted. However, the use of the strain mapping method- even in the cases where a linear mapping would otherwise be suitable, allows an unmounted element to have it's unmounted gauge factor described in a TEDs, leaving only the effects of mounting to be described independently by the user in configuration steps.

Arbitrary mapping method: Although the previous methods should support the majority of popularly used sensors, we might as well leave open a method for arbitrary mapping functions between physical and electrical units. I suggest that if the arbitrary mapping method is to be used, the next set of fields in the TEDs will be a 1451.2 style piecewise multinomial mapping function. *The 1451.2 method allows for the combination of multiple channels in the mapping method. As with my note on cold junction channels, I think there needs to be a clear undersatnding of how multichannel sensors and TEDs are going to be handled in 1451.4. Perhaps this is already clear and I just haven't caught on yet. Comments?*

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e) Demo work is stalled pending definition of development tools.

f) A Consortium may be organized following several different models for ownership and licensing of the T-Block model. More information will follow.

2) Definition of 1451.4 Class 3 Interface: T. Licht

a) Illustration proposed by P. Hufnagel may need some corrections to reflect current B&K practice. T. Licht to forward information.

b) Class 3 defines the operation of certain B&K microphones.

3) Face to face:

a) Kistler, Buffalo and Aeptec, Gaithersburg are both available for the February 2001 Face to Face Meeting. The week of Feb 19 was suggested.

b) It was decided to accept the offer from Aeptec (3e) for the 21'st to 23'rd of February. ACTION: Steven to confirm. Kang and Steven to determine site.

4) New Business:

a) Action: K. Lee review Mike Dillon's draft for letter to IEEE, proposing administration of manufacturer codes.

b) Action; P. Hufnagel to circulate Draft password to Wrking Group.

c) Action: P Hufnagel to add R. Poff, Endevco to mailing list.

d) Action: P. Hufnagel to contact M. Buckner for Jan 2001 Telcon number.

5) Next meeting, Thursday, Jan 4, 2001, at 2:00pm EST.

a) Greetings for Happy Holidays and Prosperous New Year.

b) Adjourn: 11:38am EST.