Designation: E2877 – 12

# StandardGuide for
# Standard Guide for Digital Contact Thermometers[1]

This standard is issued under the fixed designation E2877; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

## 1. Scope

1.1 This Guide describes general-purpose, digital contact thermometers (hereafter simply called "digital thermometers") that provide temperature readings in units of degrees Celsius or degrees Fahrenheit, or both. The different types of temperature sensors for these thermometers are described, and their relative merits are discussed. Nine accuracy classes are introduced for digital thermometerhes; these classes consider the accuracy of the sensor/measuring-instrument unit.

1.2 The proposed accuracy classes for digital thermometers pertain to the temperature interval of –200 °C to 500 °C, an interval of special interest for many applications in thermometry. All of the temperature sensor types for the digital thermometers discussed are able to measure temperature over at least some range within this interval. Some types are also able to measure beyond this interval. To qualify for an accuracy class, the thermometer must measure correctly to within a specified value (in units of °C) over this interval or over the subinterval in which they are capable of making measurements. Those thermometers that can measure temperature in ranges beyond this interval generally have larger measurement uncertainty in these ranges.

1.3 The digital thermometer sensors discussed are platinum resistance sensors, thermistors, and thermocouples. The range of use for these types of sensors is provided. The measurement uncertainty of a sensor is determined by its tolerance class or grade and whether the sensor has been calibrated.

1.4 This Guide provides a number of recommendations for the manufacture and selection of a digital thermometer. First, it recommends that the thermometer's sensor conform to applicable ASTM specifications. Also, it recommends minimum standards for documentation on the thermometer and informational markings on the probe and measuring instrument.

1.5 The derived SI units (degrees Celsius) found in this Guide are to be considered standard. However, thermometers displaying degrees Fahrenheit are compliant with this guide as long as all other guidance is followed.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use. Some specific hazards statements are given in Section 7 on Hazards.*

## 2. Referenced Documents

2.1 *ASTM Standards:*[2]

E230 Specification and Temperature-Electromotive Force (EMF) Tables for Standardized Thermocouples
E344 Terminology Relating to Thermometry and Hydrometry
E563 Practice for Preparation and Use of an Ice-Point Bath as a Reference Temperature
E608/E608M Specification for Mineral-Insulated, Metal-Sheathed Base Metal Thermocouples
E644 Test Methods for Testing Industrial Resistance Thermometers
E839 Test Methods for Sheathed Thermocouples and Sheathed Thermocouple Cable
E879 Specification for Thermistor Sensors for General Purpose and Laboratory Temperature Measurements
E1137/E1137M Specification for Industrial Platinum Resistance Thermometers
E2181/E2181M Specification for Compacted Mineral-Insulated, Metal-Sheathed, Noble Metal Thermocouples and Thermocouple Cable
E2593 Guide for Accuracy Verification of Industrial Platinum Resistance Thermometers
E2846 Guide for Thermocouple Verification

## 3. Terminology

3.1 *Definitions:* The definitions given in Terminology E344 apply to terms used in this guide.

3.2 *Definitions:*

3.2.1 *accuracy class, n*—class of an item that meets certain metrological requirements intended to keep errors within specified limits.

[1] This guide is under the jurisdiction of ASTM Committee E20 on Temperature Measurement and is the direct responsibility of Subcommittee E20.09 on Digital Contact Thermometers.

Current edition approved Nov. 1, 2012. Published December 2012. DOI: 10.1520/E2877–12

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

3.2.1.1 *Discussion*—This document describes accuracy classes for digital thermometers.

3.2.2 *calibration uncertainty, n*—parameter, derived from the analysis of a calibration of a measuring instrument, that characterizes the range in which the true calibration result is estimated to lie within a given confidence level.

3.2.3 *digital contact thermometer, n*—a device that measures temperature through direct contact with a sensor and provides a digital output or display of the determined value, or both.

3.2.3.1 *Discussion*—This device consists of a temperature sensor connected to a measuring instrument; this instrument measures the temperature-dependent quantity of the sensor, computes the temperature from the measured quantity, and provides a digital output or display of the temperature, or both. The sensor is sometimes located inside the instrument.

3.2.4 *measuring instrument, n*—the instrument in a digital thermometer that is used to measure the temperature-dependent quantity of the sensor.

3.2.5 *probe, n*—an assembly, including the transducer (sensor), that is used to position the transducer in the specific location at which the temperature is to be measured.

3.2.6 *reference-junction compensator, n*—a device that measures the temperature of a thermocouple's reference junction and adds to or subtracts from the reference-junction emf a compensating voltage that simulates a reference junction temperature of 0 °C.

3.2.6.1 *Discussion*—The compensating voltage may be added or subtracted electronically or digitally.

3.2.7 *response time, n*—the time required for a sensor to change a specified percentage of the total difference between its initial and final temperatures when the sensor is subjected to a step function change in temperature.

3.2.8 *sensing point, n*—the location on a temperature sensor where the temperature is (or is assumed to be) measured.

3.2.8.1 *Discussion*—A thermocouple's sensing point is its measuring junction (although the signal in the thermocouple is generated along the two thermocouple wires in regions where a temperature gradient exists). A platinum resistance thermometer contains a sensing element that may be large enough to experience spatial temperature variations; in this case the sensing point is the central point in the element where the temperature is assumed to be that measured by the platinum resistance thermometer.

3.2.9 *time constant, n*—the 63.2 % response time of a sensor that exhibits a single-exponential response.

3.2.10 *tolerance, n*—in a measurement instrument, the permitted variation of a measured value from the correct value.

3.2.10.1 *Discussion*—If a measurement instrument is stated to measure correctly to within a tolerance, the instrument is classified as "in tolerance" and it is assumed that measurements made with it will measure correctly to within this tolerance. An instrument that is not classified as "in tolerance" is classified as "out of tolerance."

## 4. Significance and Use

4.1 Digital thermometers are used for measuring temperature in many laboratories and industrial applications.

4.2 For many applications, digital thermometers using external probes are considered environmentally-safe alternatives to mercury-in-glass thermometers. (**1**)[3]

4.3 Some digital thermometers are also used as reference or working temperature standards in verification and calibration of thermometers and also in determining the conditions necessary for evaluating the performance of other measuring instruments used in legal metrology and industry.

## 5. Description of the Instruments

5.1 *Basic Description of a Digital Thermometer*

5.1.1 A digital thermometer consists of a temperature sensor, often mounted in a probe, connected to a measuring instrument. The instrument measures the temperature-dependent quantity of the sensor, computes the temperature from that measured quantity, and provides a digital output or display of the computed temperature, or both.

5.2 *Types of Digital Thermometer Sensors*

5.2.1 *Platinum Resistance Thermometer (PRT)*. The electrical resistance of a PRT's platinum element increases nearly linearly as its temperature increases, making it a temperature sensor. A PRT sensor consists of a platinum filament of fine wire or film supported by an insulating body. The sensor is usually mounted in a protective glass coating with size 2 mm to 4 mm or a sheathed probe (glass or stainless steel) with a typical outer diameter of 1.6 mm to 6.4 mm; this arrangement protects the sensor from physical damage and chemical contamination but still allows thermal transfer between the sensor and its environment. This sensor package often determines the temperature capability and accuracy of the device. The sensor is connected to a measuring instrument by electrically conducting leads. The number of leads can be 2, 3, or 4. The measuring instrument determines the resistance of the PRT's sensing element by applying a known current through it and measuring the voltage across it. Most measuring instruments for PRTs calculate the temperature of the sensor using the relevant resistance/temperature equations. The PRT calibration is defined as either a nominal resistance-temperature relationship with an interchangeability tolerance (for example, Specification E1137/E1137M) or a single sensor calibration with estimated uncertainty. A nominal relationship allows the readout device to be programmed with a single resistance-temperature relationship for a specified PRT family. Interchangeability tolerances are usually greater than 0.1 °C and increase as temperatures deviate from the ice-point. Alternatively, a sensor-specific calibration is used when a nominal curve does not exist or when the interchangeability tolerances do not support accuracy needs. PRT calibration uncertainties less than 0.01 °C are possible depending on temperature range, PRT stability and test measurement capability.

[3] The boldface numbers in parentheses refer to a list of references at the end of this standard.

Temperature range, vibration tolerability and stability (against drift) are key characteristic to consider when selecting a PRT for a particular accuracy class. PRT designs vary widely between manufacturers and can be tailored to meet the needs of specific applications. General guidelines are summarized in Table 1.

5.2.2 *Thermistor*—The electrical resistance of a thermistor (a semiconductor of blended metal oxides) varies with its temperature, making it a temperature sensor. The resistance of a thermistor can either increase as the temperature increases (positive temperature coefficient, or PTC) or decrease as the temperature increases (negative temperature coefficient, or NTC). Most thermistors that are used as temperature sensors are of the NTC type. Thermistor sensors are frequently used for temperature measurements in the range −20 to 100 °C. They are sometimes used for special applications over the ranges −196 to −20 °C and 100 to 150 °C. Thermistors have the advantages of high resolution, a fast response time, and low uncertainty over their specified range. They also have excellent stability and very good vibration tolerability. Many thermistors are either encapsulated with epoxy or sealed with a protective glass coating, resulting in a typical bead size of 0.5 mm to 3 mm. Others are mounted in a stainless steel sheath with a typical outer diameter of 0.9 mm to 6.4 mm. If the thermistor is external to the measuring instrument, it is connected to the instrument by electrical leads that are electrically insulated from the environment and from each other. An external thermistor is often located inside a protective sheathed probe; this arrangement protects the sensor from physical damage and chemical contamination but still allows thermal transfer between the sensor and its environment. Thermistors usually have two leads to measure the resistance across the thermistor material. The measuring instrument determines the combined resistance of the thermistor and leads by applying a known current through them and measuring the voltage across the ends of the leads. The instrument calculates the temperature of the thermistor using a specific resistance/temperature equation relevant to the type of thermistor. The temperature calculation requires the use of several coefficients, the values of which are stored in the instrument. For thermistor types used in clinical laboratory temperature measurements, nominal values of these coefficients may be obtained from Table 1 of Specification E879. For other thermistor types, the nominal values are generally obtained from the manufacturer. Use of the nominal values calculates temperature to within the tolerance of the thermistor type. Calibration-determined coefficient values may be entered into some instrument models, enabling more accurate temperature determination for an individual thermistor sensor. A summary of the characteristics of thermistors is listed in Table 1.

5.2.3 *Thermocouple*—A thermocouple consists of two parallel dissimilar homogeneous metal wires, called thermoelements. These thermoelements, which are usually of equal length, are joined physically and electrically at one end, called the measuring junction. The other end is called the reference junction. When there is a temperature difference between the measuring junction and reference junction, an electromotive force (emf) is produced across each thermoelement, generated in the region where temperature gradients exist. Because the thermoelements are dissimilar, an electromotive force difference (called a thermocouple emf) is produced across the reference junction. This thermocouple emf (a voltage) increases as the temperature difference increases, making the thermocouple a sensor for temperature differences. When the reference-junction temperature is known, the thermocouple may be used as a temperature sensor that determines the temperature of the measuring junction. The reference junction of the thermocouple is attached to terminals on the measuring instrument, which determines the electromotive force (emf) across the reference junction. Thermocouple wires are often covered with ceramic, fiberglass, or polymer insulations, and the measuring junction is often mounted in a sheathed stainless steel probe with a typical outer diameter of 0.2 mm to 6.4 mm for additional protection of the sensor.

The emf across the reference junction is used along with the known emf/temperature relations to calculate the measuring junction temperature. However, these relations assume that the reference-junction temperature is 0 °C. This is never the case with a digital thermometer, so a reference-junction compensator inside the measuring instrument simulates this arrangement. It measures the actual temperature of the reference junction Trj and adds to or subtracts from the reference-junction emf a compensating voltage that simulates a reference junction temperature of 0 °C. The compensating voltage may be added or subtracted either electronically (before the emf measurement) or digitally (after the emf measurement). This compensating voltage is equivalent to that which the thermocouple would produce if the measuring junction temperature were Trj and the reference junction temperature were 0 °C. The instrument then calculates the temperature of the measuring junction using the emf/temperature equation provided in Note 2 of Table 7 of Specification E230. This calculation requires use of several coefficients, the values of which are stored in the instrument. Nominal values of these coefficients may be obtained from Table 7 of Specification E230. Use of the nominal values calculates temperature to within an uncertainty determined by the stated tolerance of the thermocouple and the uncertainty of the reference junction compensation. Calibration-determined coefficient values may be entered into some instrument models; this enables an individual thermocouple sensor (or a group of thermocouple sensors made using the same wire lot) to measure temperature with an uncertainty that is less than the stated tolerance of similar uncalibrated thermocouples.

A thermocouple sensor has the advantages of a relatively large temperature range and being compact and mechanically robust. There are several types of thermocouples that may be used, each with their own temperature ranges and tolerances. Some of the more commonly used thermocouples are types E, J, K, N, R, S, and T. The respective temperature ranges and characteristics of these thermocouples are shown in Table 1.

Thermocouples can be very stable if used only at temperatures near ambient. Their stability decreases at higher temperatures due to oxidation-related drift. Therefore, thermocouple uncertainties can be reduced considerably if the calibration/