FLUKE®

Calibration

# Understanding uncertainties associated with the 5128A RHapid-Cal Humidity Generator

Technical Note

The Fluke Calibration 5128A RHapid-Cal Humidity Generator provides a portable, stable test environment for calibrating a large workload of humidity probes and loggers in the laboratory or on-site in the field. Sources of error (uncertainty) need to be identified and accounted for when calculating measurement performance of a humidity generator. The purpose of this technical note is to help calibration professionals understand and evaluate the 5128A RHapid-Cal measurement uncertainty when used in a humidity calibration process.

Figure 1. Typical 5128A RHapid-Cal setup for calibrating humidity sensors

## Temperature and humidity uniformity

Uncertainty due to temperature non-uniformity inside the test chamber is a large source of error in humidity generators. The design, specifications, and factory calibration of the 5128A help minimize and control non-uniformity. The 5128A uniformity specification applies to a clearly defined working area (see Figure 2) so the user knows exactly where to place humidity sensors. In the ISO 17025 accredited system calibration, included standard with each 5128A unit, eight temperature sensors verify chamber uniformity in the working area.

Humidity uniformity can be difficult to evaluate. Sometimes manufacturers specify humidity generators for only temperature uniformity, or they specify humidity uniformity for only one humidity value. Humidity uniformity is based on temperature uniformity because water molecules in air (water vapor) evenly disperse in a closed system unless temperature is not uniform. Also, since relative humidity (RH) is the percent of water vapor saturation at a particular temperature, it varies with air temperature.

Calculating humidity uniformity from temperature uniformity is complicated. One method is to use a dew-point-to-RH calculator to determine a temperature-to-RH sensitivity coefficient for a

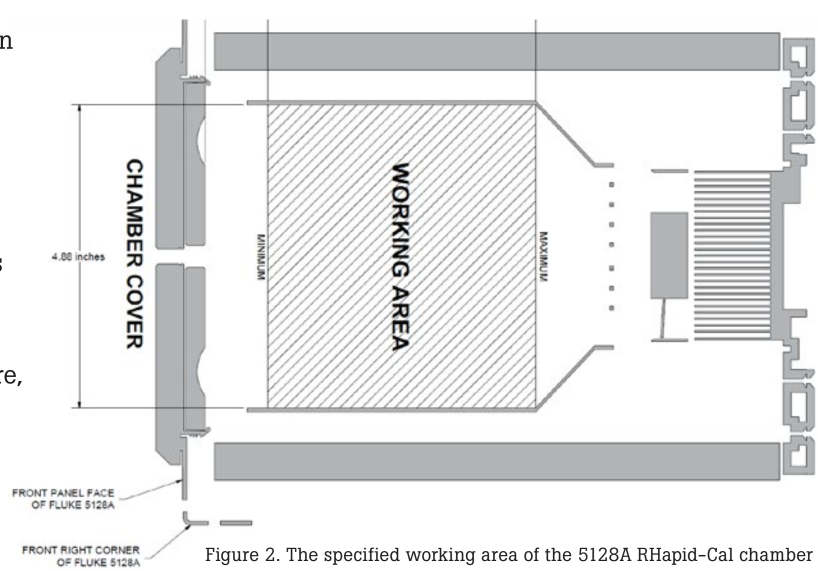


Figure 2. The specified working area of the 5128A RHapid-Cal chamber

given value of temperature and humidity. There are several reliable RH calculators available on the internet. The calculation is done by selecting the required dew point, air temperature, and RH values. Then either the air temperature is changed in the calculator by 1 °C to determine the resulting change in RH or the RH is changed by 1 % rh to determine the corresponding change in temperature. Equation 1 gives an example of calculating humidity uniformity from the 5128A temperature uniformity specification at 23 °C, 45 % rh. Table 1 provides the RH uniformity values for several values of RH. Table 2 gives an example of the 5128A temperature uniformity results measured during factory calibration process.

### Tips for reducing uniformity uncertainty

When operating any humidity chamber, it is important to minimize the effects of temperature non-uniformity that are introduced by the user during Device Under Test (DUT) calibration. Temperature non-uniformity can be reduced by ensuring proper measurement setup. A good setup removes effects from ambient conditions and ensures that the chamber uniformity is within specification. Temperature gradients can occur when instruments or cables extend from room temperature to chamber temperature through the chamber door, allowing heat to enter the chamber or leave the chamber. Sensors and cables should be sufficiently inserted into the chamber to minimize temperature gradients from stem effect. The 5128A is calibrated with the reference temperature sensor placed close to the chamber sensor. Therefore, placing test sensors in the back of the chamber provides the best measurement results (see Figure 3). Use the provided grommets and twist-tight access ports to ensure a good seal around the DUT (device under test).

## Stability

5128A stability (repeatability) is specified as the standard deviation (1-sigma, k=1) of humidity and temperature inside the chamber measured over a 5-minute period after settling at a set point (see Table 3). The 1-sigma level of specification coverage was chosen for user convenience. Instruments that are able to calculate and display average and standard deviation usually indicate, by definition, 1-sigma standard deviation. Also spreadsheet calculations, such as the stdev() function in Microsoft Excel, calculate 1-sigma standard deviation. This makes it easy to compare measurement results with specified stability.

### Tips for maintaining good stability

The 5128A controller is designed to transition and settle quickly to temperature and humidity set points, so specified stability is typically achieved after a few minutes of soak time. The 5128A is

Equation 1. Example of calculating humidity uniformity from the 5128A specification at 23 °C, 45 % rh.

$$RH\_Uniformity = T\_Uniformity * \frac{dRH}{dT} = 0.12\ °C * 2.7\ ^{\%\ rh}/_{°C} = 0.33\ \%\ rh$$

| **Table 1: Examples of impact of temperature uniformity on humidity uniformity** | | | | | | | |
|---|---|---|---|---|---|---|---|
| **RH** | 7 % rh | 20 % rh | 30 % rh | 45 % rh | 70 % rh | 80 % rh | 95 % rh |
| **Sensitivity, % rh/°C** | 0.4 | 1.2 | 1.9 | 2.7 | 4.1 | 4.9 | 5.8 |
| **T Uniformity (k=2.58, 99 %)** | 0.12 °C | | | | | | |
| **RH Uniformity (k=2.58, 99 %)** | 0.05 % rh | 0.14 % rh | 0.23 % rh | 0.33 % rh | 0.49 % rh | 0.58 % rh | 0.69 % rh |

Note: RH to T sensitivity varies slightly depending on the air temperature but is mostly dependent on the RH value. The values shown are based on air temperature at 23 °C.

**Table 2: Example of 5128A temperature uniformity results measured during factory calibration process**

| **Set Point** | **Measured Non-Uniformity (°C)** | **Limit (°C)** | **Status** | **Expanded Uncertainty (k=2, °C)** |
|---|---|---|---|---|
| 18 °C | 0.070 | 0.120 | Pass | 0.02 |
| 23 °C | 0.020 | 0.120 | Pass | 0.02 |
| 28 °C | 0.070 | 0.120 | Pass | 0.02 |

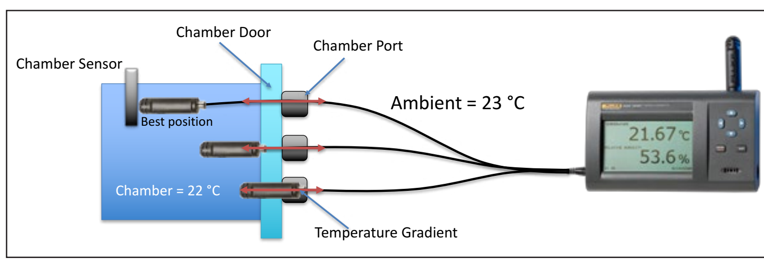


Figure 3. Example of proper DUT placement to reduce uncertainty due to non-uniformity and stem effect

**Table 3: 5128A stability specifications - calibrated range**

| | Specification (k=1, 66.7 %) |
|---|---|
| RH range: 7 % rh to 95 % rh | 0.15 % rh |
| Temperature range: 18 to 28 °C | 0.05 °C |

Note: See Operators Manual for stability specifications outside the calibrated humidity and temperature ranges shown in Table 3.

a sealed system that recirculates chamber air through the drier and humidifier systems. Stability improves as the controller and system are allowed to further stabilize and equilibrate so the system can arrive at a static condition with minimal temperature flux. This provides better stability than a system that draws ambient or shop air through the drier and humidifier systems. Temperature stability as good as +/- 0.005 °C, and RH stability as good as 0.02 % rh are routinely observed in a 5128A calibration process where ramp-and-soak times of 30 minutes are used (see Figure 4). Longer soak time may also be required for the DUT depending on sensor construction. Stability is optimized by ensuring a good seal on the door and around the sensors (or cables), not overloading the chamber, and avoiding materials that absorb water.

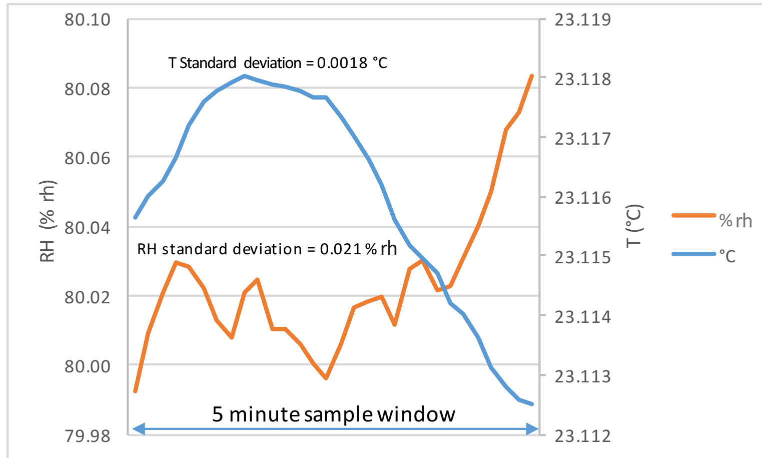


Figure 4. Example of temperature and humidity stability measured in a 5128A during the factory calibration process. The results were measured with a reference digital thermometer system and a precision chilled mirror hygrometer after 30-minute ramp and soak time.

## Short-term and long-term reproducibility and drift

The 5128A calibrated display reads a chamber sensor comprised of a precision capacitive humidity sensor and a precision platinum thin-film temperature sensor that have excellent short-term repeatability performance. Long-term drift is minimized by keeping the sensor inside the chamber to protect it from contamination and other sources of drift such as handling and mechanical shock. Placing items in the chamber with significant outgassing (where volatile contaminants evaporate off) can cause the chamber humidity sensor to drift and should be avoided. Also, the chamber should be used and stored with the door on to keep external contaminants from getting inside. As with any precision calibration instrument, drift is reduced by handling the instrument carefully and keeping it in good operating condition.

To control long-term drift, a calibration program should always consider the use of intermediate checks with reliable check standards or reference standards to monitor drift of important measurement parameters. It is recommended drift be monitored by using a conservative calibration interval when the instrument is new. Then extend the calibration interval as drift is verified in the calibration process. To help counter potential drift, Fluke Calibration uses drift-based guard band limits in the 5128A calibration. The drift guard band limits allow for drift that may occur as the instrument is used throughout the calibration interval.

## Loading effect

The 5128A does not have a loading effect specification. This is because RH instruments vary in size, shape, and construction so it is impossible to base a specification on a typical representative instrument.

**Table 4: 5128A calibration uncertainties**

| Relative Humidity | 7 % rh | 20 % rh | 30 % rh | 45 % rh | 70 % rh | 80 % rh | 95 % rh |
|---|---|---|---|---|---|---|---|
| $U_{RH}$, k=2, 95 % | 0.30 % rh | 0.30 % rh | 0.30 % rh | 0.35 % rh | 0.50 % rh | 0.55 % rh | 0.65 % rh |

| Temperature | 18 to 28 °C |
|---|---|
| $U_T$, k=2, 95 % | 0.068 °C |

The 5128A has a chamber mixing insert and chamber mixing fan that mix the air and maintain temperature uniformity when multiple DUTs are installed. When a DUT contributes a small amount of additional heat into the chamber, the air mixing will help alleviate any localized temperature gradients. However, DUTs that contribute significant heat loads, such as DUTs with built-in displays, may require additional uncertainty to be added. In these cases, Fluke Calibration recommends studying the temperature uniformity in the system and adjusting measurement uncertainty as needed.

## Calibration uncertainty

Each 5128A receives a 17025 accredited system calibration. The 5128A system (generator and sensor calibrated together) is calibrated with a specially calibrated chilled-mirror dew point hygrometer and a reference digital thermometer system for lower uncertainties. The uncertainty analysis includes all known sources of uncertainty at the time of calibration, including uncertainties related to the reference instrumentation and uncertainties contributed by the 5128A (see Table 4).

The calibration is performed at twelve different combinations of humidity and temperature set points, with each measured point analyzed with seven points of performance criteria to ensure the 5128A meets all published specifications, meets all calibration uncertainty process limits, and is functioning properly (see Figure 5). The calibration process also ensures reliable calibration results using risk analysis algorithms to ensure Pass and Fail declarations are made with a high degree of confidence (2 % or less risk of False Accept). As-Left guard banding is applied to protect against potential drift that may occur during a 12-month calibration interval.

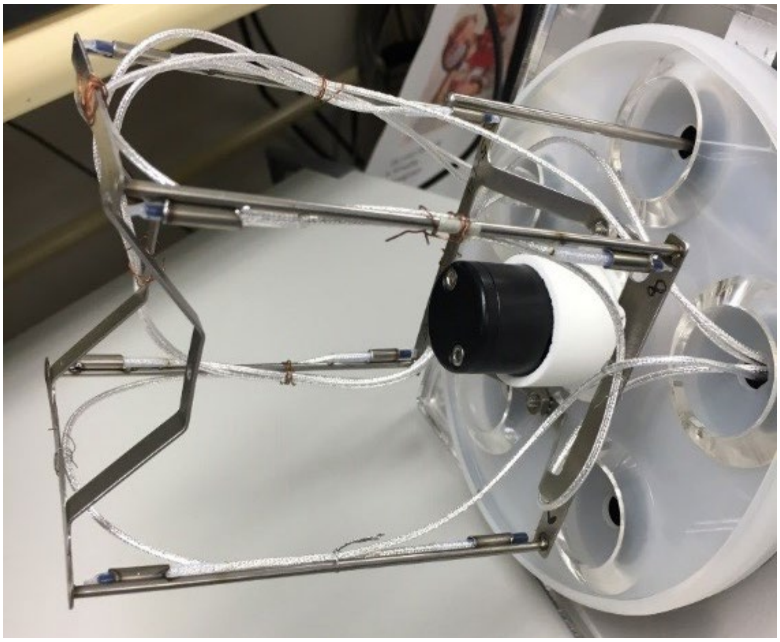

Figure 5. Calibration jig placed in the 5128A during factory calibration. Seven sensor test points at twelve different combinations of humidity and temperature set points are tested in the chamber to ensure 5128A performance.

## Applying the 5128A specifications

The 5128A is designed to provide its own traceability with the calibrated display and temperature-mapped chamber. It can also be used with external reference standards to provide more calibration flexibility and to improve calibration uncertainties. This section provides examples of uncertainty analyses that demonstrate how the 5128A specifications can be applied in two typical calibration scenarios.

### Scenario 1: Using the 5128A calibrated display as the humidity and temperature reference

The 5128A humidity and temperature display accuracy specifications account for the possible errors and sources of uncertainty that may occur during a 12-month calibration interval. This allows the user to simply add in the uncertainties

**Table 5: 5128A humidity display error analysis (at 45 % rh, 23 °C)**

| Source of uncertainty | Value | Unit | $U_T$ to $U_{RH}$ Multiplier | *k* Divisor | Description |
|---|---|---|---|---|---|
| Calibration uncertainty | 0.35 | % rh | 1 | 2 | The uncertainty assigned to the calibration of the 5128A built-in display. |
| Long-term drift | 0.40 | % rh | 1 | 1.73 | Allowed system drift that includes sensor and electronics short and long-term drift. This is dependent on how the 5128A is handled during the 12-month calibration interval. |
| Display resolution | 0.05 | % rh | 1 | 1.73 | 5128A display resolution of 0.1 % rh. |
| Chamber uniformity | 0.12<br>0.33 | °C<br>% rh | 2.72<br>1 | 2.58<br>2.58 | Based on 5128A temperature uniformity specification. Shown both in temperature and humidity for completeness. |
| Measurement stability | 0.15 | % rh | 1 | 5.48 | This is the uncertainty (standard error) of the RH mean obtained from measuring over a 5-minute period where n ≥ 30 (5.48 = $\sqrt{30}$), based on the published specification of 0.15 % rh. |
| Total standard uncertainty (k=1) | 0.32 | % rh | | | |
| Total expanded uncertainty (k=2.58) | 0.82 | % rh | | | |
| Absolute instrumental uncertainty (k=2.58) | 1.0 | % rh | | | Absolute Instrumental Uncertainty is the humidity display specification as listed in the 5128A Operators Manual. |

| Table 6: 5128A temperature display error analysis (18 to 28 °C) | | | | |
|---|---|---|---|---|
| **Source of uncertainty** | **Value** | **Unit** | ***k* Divisor** | **Description** |
| Calibration uncertainty | 0.068 | °C | 2 | The uncertainty assigned to the calibration of the 5128A temperature display. |
| Long-term drift | 0.060 | °C | 1.73 | Allowed system drift that includes sensor and electronics short and long-term drift. This is dependent on how the 5128A is handled during the 12-month calibration interval. |
| Display resolution | 0.050 | °C | 1.73 | 5128A display resolution of 0.1 °C. |
| Chamber uniformity | 0.120 | °C | 2.58 | Based on 5128A temperature uniformity specification. |
| Measurement stability | 0.050 | °C | 5.48 | This is the uncertainty (standard error) of the temperature mean obtained from measuring over a 5-minute period where n ≥ 30 (5.48 = √30), based on the published specification of 0.05 °C. |
| Total standard uncertainty (k=1) | 0.074 | °C | | |
| Total expanded uncertainty (k=2.58) | 0.190 | °C | | |
| Absolute instrumental uncertainty (k=2.58) | 0.2 | °C | | Absolute Instrumental Uncertainty is the temperature display specification as listed in the 5128A Operators Manual. |

contributed from the DUT, such as display resolution, measurement repeatability, and short-term reproducibility to easily calculate total measurement uncertainty. Tables 5 and 6 provide details about how the display accuracy specifications are calculated.

### Scenario 2: 5128A with external humidity and temperature reference

The 5128A supplementary specifications allow a user to build up a measurement uncertainty analysis easily by using external humidity and temperature references to improve system uncertainty. A chilled-mirror hygrometer can improve humidity measurement uncertainty significantly if the uncertainties are properly accounted for. A reference thermometer system can improve system temperature uncertainty and can help reduce temperature uniformity uncertainty by placing a temperature sensor or sensors close to the DUT(s).

A challenge with using a chilled-mirror hygrometer is converting dew point specifications to RH specifications. Just like converting air temperature specifications to humidity equivalent specifications, the math to directly convert dew point uncertainty to RH uncertainty is complicated. A simple solution for the conversion is to use a dew-point-to-RH calculator to determine dew point temperature to humidity conversion multipliers. Enter the required air temperature value and dew (or frost) point value into the calculator to calculate the corresponding RH value. Then change the dew point value by 1 °C and calculate RH again. The change in RH is the RH sensitivity to a 1 °C change in dew point and is a simple multiplier for converting dew point specifications.

Another challenge with using dew point hygrometers is understanding the manufacturer's specifications and what is included in accuracy statements. In some cases calibration uncertainty may not be included. It is important to consult with the chilled-mirror manufacturer to understand what uncertainties are applied when using a chilled-mirror. Table 7 provides examples of how typical chilled-mirror hygrometer dew point accuracy specifications convert to RH equivalents at different levels of humidity. Dew-point to

| Table 7: Sample dew point to RH specification conversions | | | | | | |
|---|---|---|---|---|---|---|
| **RH value, % rh** | 7 | 20 | 45 | 45 | 80 | 95 |
| **Air temperature, °C** | 18 | 23 | 23 | 28 | 23 | 23 |
| **Dew point, °C** | -18.4 | -1.2 | 10.4 | 15.0 | 19.4 | 22.2 |
| **dRH/dTdewpoint sensitivity, % rh/°C** | 0.59 | 1.46 | 3.00 | 2.91 | 4.99 | 5.80 |
| **Dew point accuracy, °C** | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 |
| **RH accuracy, % rh** | 0.06 % rh | 0.15 % rh | 0.30 % rh | 0.29 % rh | 0.50 % rh | 0.58 % rh |

| Table 8: 5128A with chilled-mirror and reference thermometer (at 23 °C and 45 % rh) | | | | | |
|---|---|---|---|---|---|
| **Source of uncertainty** | **Value** | **Unit** | **T to RH Multiplier** | ***k* Divisor** | **Description** |
| Reference dew point long-term drift | 0.050 | °C | 3.00 | 2 | Chilled-mirror long-term drift specification |
| Reference dew point calibration uncertainty | 0.080 | °C | 3.00 | 2 | Calibration uncertainty of the chilled-mirror dew-point measurement |
| Reference dew point reproducibility | 0.050 | °C | 3.00 | 2 | Chilled-mirror short-term reproducibility specification |
| Reference dew point measurement stability | 0.050 | °C | 3.00 | 5.48 | Contribution of chamber stability to dew point mean measured over a 5-minute period, n ≥ 30 (5.48 = square-root of 30). This is the dew point equivalent to 0.15 % rh. Can be reduced with a longer soak time. |
| Reference temperature readout 1-year uncertainty | 0.003 | °C | 2.72 | 2 | Reference readout 1-year uncertainty (includes calibration and long-term drift uncertainties) |
| Reference temperature probe calibration uncertainty | 0.006 | °C | 2.72 | 2 | |
| Reference temperature probe 1-year drift | 0.010 | °C | 2.72 | 2 | 1-year allowed drift of the reference temperature probe |
| Reference temperature probe reproducibility | 0.003 | °C | 2.72 | 2 | Temperature probe short-term repeatability (reproducibility) limit |
| Reference temperature stability | 0.050 | °C | 2.72 | 5.48 | Contribution of chamber stability to temperature mean measured over a 5-minute period, n ≥ 30 (5.48 = square-root of 30). This is the 5128A temperature stability specification. Can be reduced with a longer soak time (i.e. 30 minutes). |
| Chamber temperature non-uniformity | 0.120 | °C | 2.72 | 2.58 | Based on the 5128A chamber temperature uniformity specification. Can be improved by placing DUT sensors closer to the reference temperature sensor. |
| | | | | | |
| Total standard uncertainty (k=1) | 0.21 | % rh | | | |
| Total expanded uncertainty (k=2) | 0.42 | % rh | | | |

RH conversion requires the RH value, air temperature value, and dew-point value.

Table 8 provides an example of an uncertainty analysis using the 5128A with external humidity and temperature references. Tips for improving some uncertainties are also provided. Smaller uncertainties, such as reference display resolution,

This following equation provides an example for calculating RH accuracy from dew-point accuracy at T_Air = 23 °C, RH = 95 % rh:

$$Accuracy\_RH = Accuracy\_DP * \frac{dRH}{dT_{DP}} = 0.1°C * 5.8 \ {}^{\%\,rh}\!/_{°C} = 0.58\ \%\ rh$$

are not shown to allow focus on the more significant uncertainties. Uncertainty contributions from the DUT are also not included. The reference equipment set used in this example includes a Fluke Calibration 1586A Super-DAQ Precision Temperature Scanner, 5611T Reference Thermistor Probe, and a precision chilled mirror hygrometer.



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