# Temperature and Relative Humidity Calibration System

**Speaker: Norman Willgress**

**Authors: Rick Walker, Alan Cordner**

**Fluke Corp., Hart Scientific Div.**

**799 E Utah Valley Drive**

**American Fork, UT 84003-9775**

# Team

- Alan Cordner – software, assembly, testing
- Tom Wiandt – metrology
- Dave Farley – mechanical
- Rick Walker – design, analysis

# Objective

- Construct a calibration system to be used by manufacturing to calibrate the temperature and relative humidity measurement functions of a new digital environmental data recorder

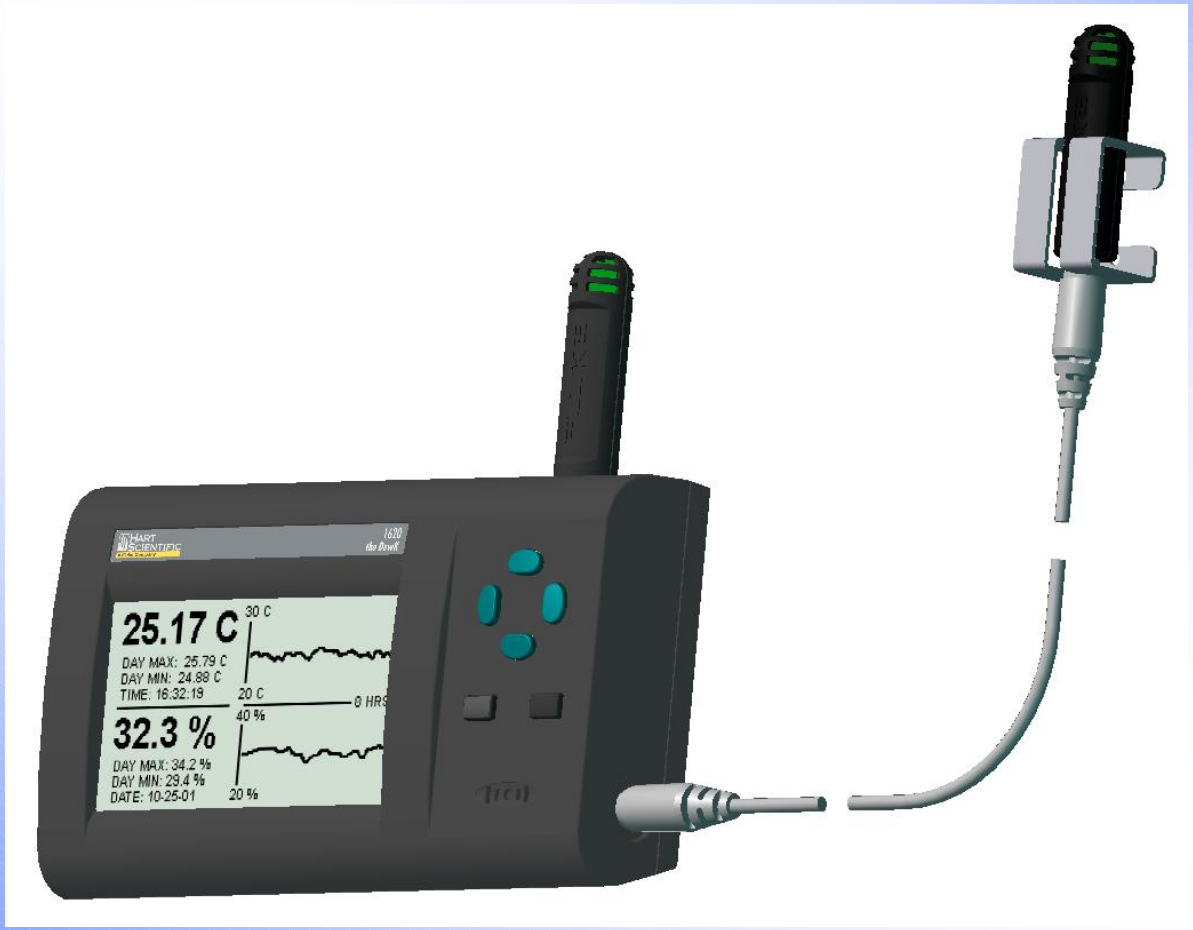
# Outline

- Application background
- Description of the instrument
- Calibration system requirements, uncertainties
- Design of the calibration system, equipment
- Temperature uncertainty analysis
- Relative humidity uncertainty analysis
- Results

# Background

- Environmental control is important in calibration work
- Ambient temperature and relative humidity affect processes and measurements
- ±0.5ºC, ±5% RH requirement not unusual
- Conditions must be monitored, recorded, reported
- Chart recorders have been used
- Digital recorders recently available—many advantages, including better accuracy
- Calibration is a challenge—the calibration system must be carefully designed and operated

# Digital temperature/relative humidity recorder



# Features

- Display/processing unit—non-volatile memory
- Two detachable sensor units
- Sensor extension cables, up to 30 m (100 ft.)
- Sensor units contain temperature and relative humidity sensing components
- Analog-to-digital conversion within the sensor unit
- Sensors contain memory—calibration, ID
- Adjustable digital correction coefficients—stored in the sensor
- Sensor calibration is independent of the display/processing unit

# Sensor specifications

- Model H temperature accuracy: **±0.125ºC**
- Model H temperature range: 16 to 24ºC
- Model H relative humidity accuracy: **±1.5%**
- Model H relative humidity range: 20 to 70%

- Model S temperature accuracy: ±0.25ºC
- Model S temperature range: 15 to 35ºC
- Model S relative humidity accuracy: ±2%
- Model S relative humidity range: 20 to 70%

# Sensor characteristics

- 19 mm (0.75 in.) diameter, 78 mm (3.1 in.) length
- Self-heating from electronic components in the sensor unit
- Self-heating can be largely corrected by calibration
- Self-heating is slightly dependent on air velocity
- Keep sensor units apart
- Hysteresis of the RH device must be considered
- Digitally adjustable slope and offset corrections
- Three-point calibration—tests nonlinearity, provides redundancy

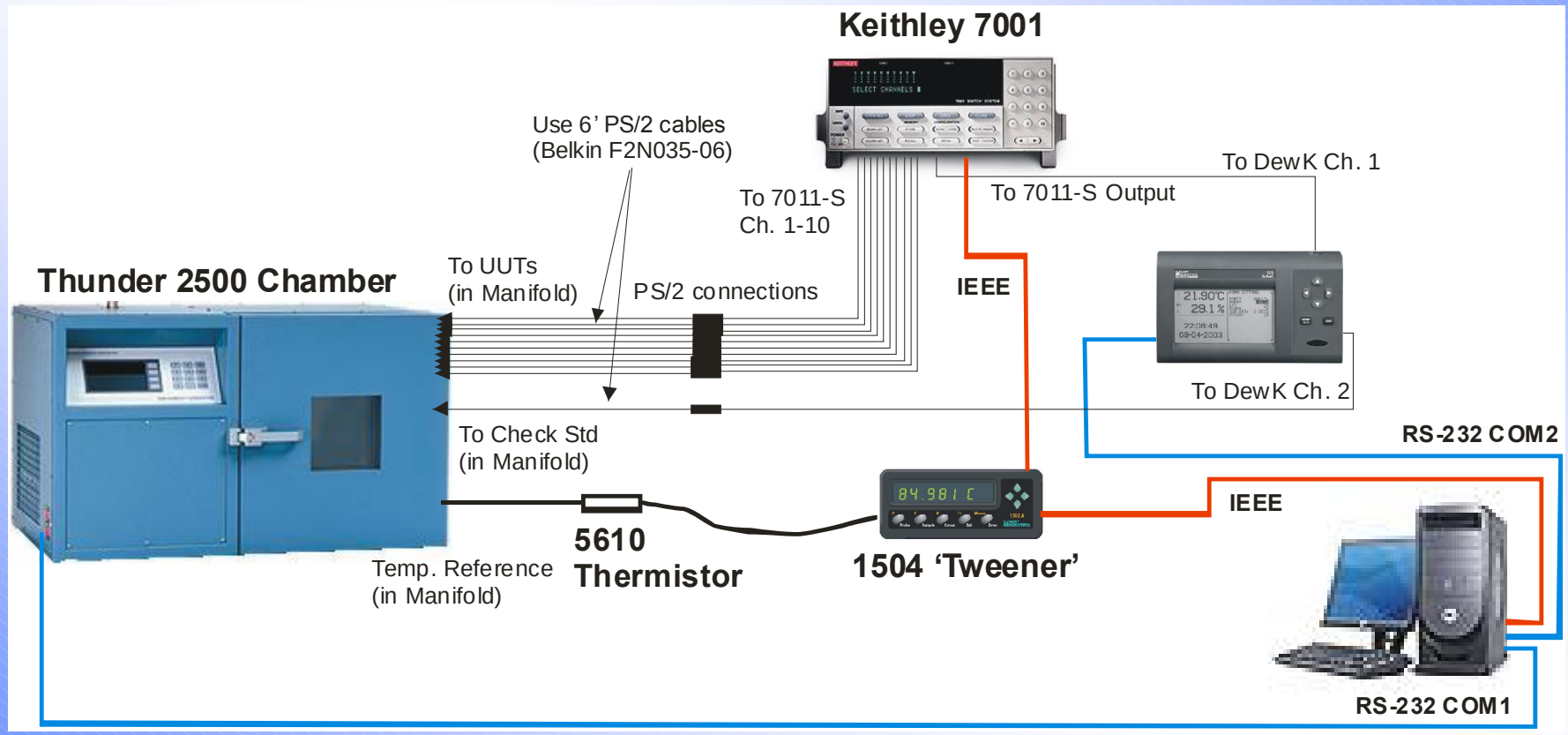
# Calibration requirements

- T ref. uncertainty (*k*=2, 4:1): 0.031ºC
- T cal. uncertainty (*k*=2, 3:1): 0.041ºC
- RH ref. uncertainty (*k*=2, 4:1): 0.37%
- RH cal. uncertainty (*k*=2, 3:1): 0.5%
- Three temperature points from 15 to 35ºC
- Three RH points from 20 to 70%
- Ability to calibrate 10 sensor units at once
- Controlled air velocity limits self-heating uncertainty
- Automated
- One display/processing unit, switching device
- All devices powered continuously
- Use of a check standard

# Equipment

- Model 2500ST two-pressure humidity generator
  - stable and accurate relative humidity, stable temperature
- Model 5610 thermistor probe
  - measure temperature
- Model 1504 thermometer readout
  - measure thermistor resistance, display temperature
- Model 1620 recorder display/processing unit
  - read DUT and check standard measurements
- Model 1620 recorder sensor unit
  - check standard
- Model 7001/7011 switch
- Test manifold
  - hold devices, control air flow, thermal isolation, uniformity
- Computer and software

# T/RH calibration system



# 2500 two-pressure humidity generator

- Covers T and RH range of interest
- Controls temperature and relative humidity
- RH standard uncertainty: 0.14%
- Large chamber
- 20 l/min air flow
- Clean, dry, 550 kPa (80 PSIG) air supply
- RS-232 serial interface to computer
- Temperature accuracy inadequate for this application

# Temperature reference

- 5610 thermistor stability (*k*=2): 0.0050ºC
- Thermistor calibration (*k*=2): 0.0022ºC
- Thermistor characterization (*k*=2): 0.0020ºC
- Readout uncertainty (*k*=2): 0.0024ºC
- Combined standard uncertainty: 0.0031ºC

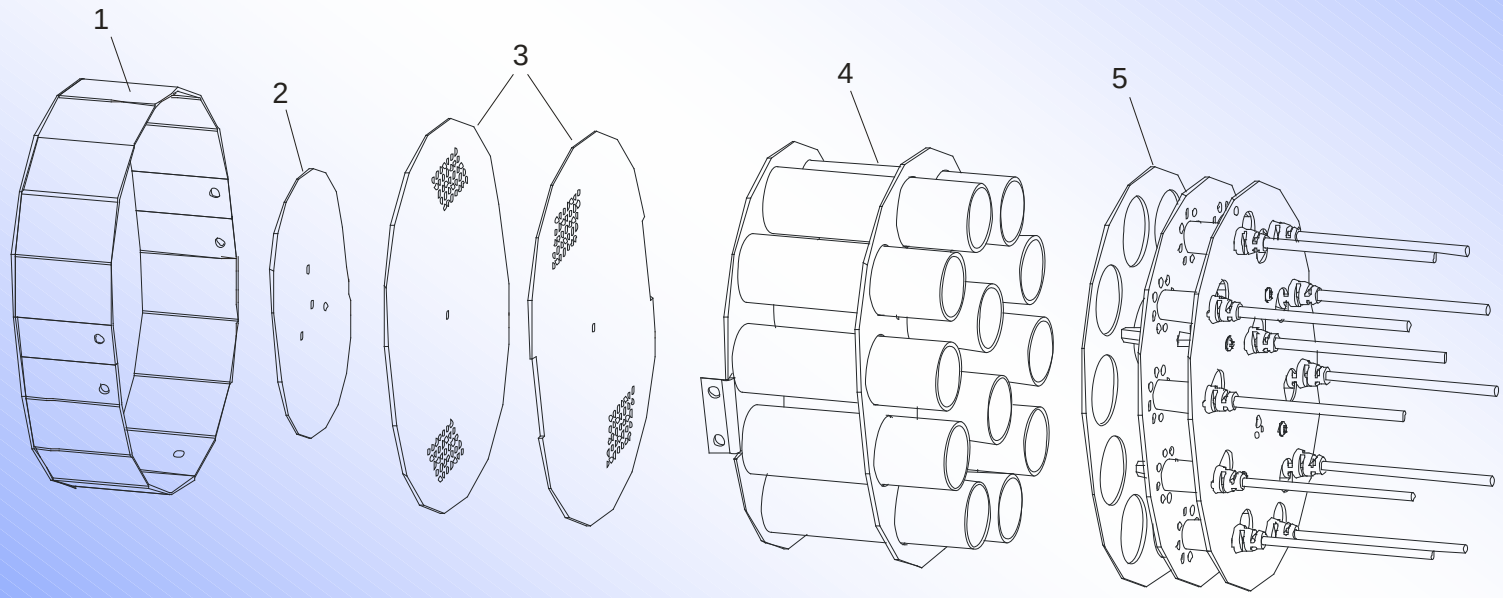
# Check standard

- Off-the-shelf sensor unit
- Stays with the calibration system
- Processed along with the DUTs each time
- No adjustment of its characterization
- History kept
- Excessive error can be recognized

# Test manifold

- Controls air flow to DUTs
- Holds 10 DUTs, check standard, thermistor, control probe
- Thermally isolates sensors from each other to avoid mutual self-heating
- Facilitates loading and removing devices

# Manifold exploded view



# Temperature uniformity

- Testing revealed temperature differences as much as 0.042ºC within the test manifold
- Temperature gradients were repeatable
- Profiling procedure quantified the bias at each location
- Corrections were applied
- Errors reduced to within ±0.01ºC

# Calibration steps

| Step | Phase | Measurement | Temperature | Relative humidity |
|---|---|---|---|---|
| 1 | as-found | T1 | 16°C | 45% |
| 2 | as-found | T2 | 20°C | 45% |
| 3 | as-found | RH2 | 20°C | 45% |
| 4 | as-found | T3 | 24°C | 45% |
| 5 | as-found | RH1 | 20°C | 20% |
| 6 | as-found | RH3 | 20°C | 70% |
| 7 | adjustment | - | - | - |
| 8 | as-left | RH3 | 20°C | 70% |
| 9 | as-left | RH1 | 20°C | 20% |
| 10 | as-left | T1 | 16°C | 45% |
| 11 | as-left | T2 | 20°C | 45% |
| 12 | as-left | RH2 | 20°C | 45% |
| 13 | as-left | T3 | 24°C | 45% |

# Settling

- 2 to 3 hours to allow the chamber and sensors to settle
- Settling standard uncertainty: 0.01ºC, 0.07%

# Computer

- Controls the humidity generator, sets set-points
- Reads temperature from the reference
- Monitors settling
- Controls switch for DUTs
- Applies temperature corrections per location
- Reads the check standard
- Reads each DUT
- Calculates errors
- Calculates new characterization coefficients
- Records results
- Reports pass/fail

# Other issues

- Sensor hysteresis *u*: 0.0ºC, 0.15%
- DUT noise, round-off: 0.0029ºC, 0.029%
- Air speed x self-heating: 0.0025ºC
- Temperature extrapolation: 0.0006ºC
- No noticeable DUT drift during calibration
- Calibration laboratory temperature and relative humidity are controlled, recorded

# Temperature uncertainties

| Description | Type | Standard uncertainty, °C |
|---|---|---|
| Temperature reference | B | 0.0031 |
| Manifold nonuniformity (corrected) | A | 0.01 |
| Settling, stability | A | 0.01 |
| Air speed and self-heating | B | 0.0025 |
| DUT hysteresis | A | 0.0 |
| DUT drift | A | 0.0 |
| DUT noise and round-off | A | 0.0029 |
| Calibration point extrapolation | A | 0.0006 |
| Combined standard uncertainty | | 0.015 |
| Combined expanded uncertainty, $k$=2 | | **0.030** |

# Relative humidity uncertainties

| Description | Type | Standard uncertainty, % |
|---|---|---|
| Humidity generator | B | 0.14 |
| Settling, stability | A | 0.07 |
| Temperature nonuniformity | A | 0.06 |
| DUT hysteresis | A | 0.15 |
| DUT drift | A | 0.0 |
| DUT noise and round-off | A | 0.029 |
| Combined standard uncertainty | | 0.227 |
| Combined expanded uncertainty, $k$=2 | | **0.454** |

# Testing the calibration system

- Observed repeatability of calibration
- Compared with single-sensor calibration
- Compared the humidity generator with a dew-point hygrometer

# Results

- Uncertainty analysis showed the calibration system can be expected to meet the accuracy requirements
- Testing showed errors are within the expected range
- The calibration system met the reliability, through-put, and convenience requirements of manufacturing

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# Thank you.

# Questions?