HIGH ACCURACY HUMIDITY MEASUREMENT USING THE CS114 OR CS124

This application note discusses the following:

- Sensing Methods
  - Psychrometric Method; Chilled Mirror Hygrometers; Mechanical hygrometers; Electronic Humidity Sensors
- Why is it so hard to measure humidity accurately
  - Calibration; Measurement in Air; Wide Dynamic Range; Temperature
- Understanding humidity specifications
  - Accuracy; Hysteresis; Noise / Repeatability; Interchangeability; Response time; Long term stability / Immunity to contaminants; Soldering / Storage and operational conditions; Power Consumption
- Advantages of using ChipSensors humidity sensors

1 SENSING METHODS

A wide range of techniques are employed to measure humidity. These range from simple mechanical indicators, to highly complex and expensive analytical instruments. In general, measuring humidity (whether it is relative humidity, dew point, absolute humidity, equivalent wet bulb temperature) is not a trival task. Many of the instruments currently available have poor accuracy, narrow bandwidth, contamination issues, hysteresis and sensor drift over temperature and time. These errors often mean that regular calibration is required – which is both inconvenient and expensive and doesn't necessarily fix all the issues.

These instruments are often large, awkward, and expensive. Discussed below, are the different methods of humidity sensing.

1.1 Psychrometric Method

A psychrometer is the oldest method for measuring humidity and is more commonly known as the wet and dry bulb method. A psychrometer consists of two thermometers, one with a dry bulb and the other with a wet bulb. Evaporation from the wet bulb lowers the temperature, so that the wet-bulb thermometer usually shows a lower temperature than that of the dry-bulb thermometer. The amount of evaporation is dependent on the relative humidity of the air. Using the ambient temperature (dry-bulb thermometer) and the difference in temperatures (difference between dry bulb and wet bulb temperatures) the relative humidity can be looked up on a psychrometric chart. Looking up the %RH on a chart for every measurement is both time-consuming and cumbersome, although nowadays this can be done by a microcontroller.

A psychrometric sensor can achieve good precision with %RH resolutions of 0.1%, humidity ranges from 10 - 100%, at temperatures from 0°C to 60°C, and accuracy's of 2%. The disadvantages of a psychrometric sensor are a slow response time and expensive cost.

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1.2 Chilled Mirror Hygrometers

The chilled mirror hygrometer is considered the most accurate and reliable hygrometer commercially available. Chilled mirror hygrometers use a cooled mirror and optoelectronic mechanism to detect condensation on the mirror surface, with the temperature at which condensation occurs being accurately measured. The system is configured so that an LED reflects light off the mirror at an angle of approximately 45 degrees, and a photo-transistor is used to detect the reflected light. The temperature of the mirror is electronically controlled. The system works by cooling the mirror's surface below ambient temperature until condensation forms, causing the LED's light to scatter. This results in a sudden drop in the output of the photo-transistor. At which point, the surface temperature of the mirror is read using a temperature sensor such as an RTD or thermistor. This temperature is the dew point, and from this all humidity values can be calculated. With a feedback loop, the cooling or heating of the mirror continuously tracks the dew point.

The chilled mirror method is the most stable and accurate method to determine relative humidity. However, it is crucial to keep the mirror clean and to ensure that the temperature sensor and mirror are of high quality. This method operates over the full humidity range (0-100%RH) and can be used for numerous gases at many pressures. Chilled mirror hygrometers instruments are bulky and very expensive.

1.3 Mechanical Hygrometers

Mechanical hygrometers use sensing elements, whereby a mechanical property of the sensor varies with humidity. The most common example is the animal hair hygrometer, which uses a piece of animal hair kept under tension. As the humidity increases the hair becomes more flexible and stretches. A strain gage monitors the displacement caused by a change in the moisture content of the air. The output of the strain gage is directly proportional to the relative humidity. Mechanical hygrometers are generally compact, reliable, and inexpensive.

1.4 Electronic Humidity Sensors

Electronic humidity sensors are typically either resistive or capacitive sensors, whereby the resistance (or capacitance) between two electrodes varies with humidity. Technology advances have made these sensors more accurate, compact, and stable in recent years, making them a popular choice in industry.

A capacitive sensor consists of two electrodes, separated by a dielectric. As the water vapour in air increases (decreases) the dielectric constant of the dielectric changes resulting in a higher (or lower) measured capacitance. A resistive sensor consists of two electrodes, separated by a conductive layer. As the humidity in the air increases (or decreases) the conductivity of the sensing layer changes, altering the resistance between the two electrodes. New techniques in producing thin films have made these, accurate, stable, and easy to manufacture in large quantities. The choice of material assures fast response times with little hysteresis.

Electronic sensors are limited by their instability with respect to time (drift) which is caused in particular by wide variations in temperature & humidity or the presence of pollutants. Regular calibration often forms an integral part of their effective use and maintenance.

2 WHY IS IT SO HARD TO MEASURE HUMIDITY ACCURATELY?

Why is there such a difficulty in measuring relative humidity? Top of the range relative humidity sensors today boast of accuracies ranging from ± 1% to 4% RH. Today's humidity calibrators have accuracies of ±0.5% RH. While these figures don't necessarily suggest high accuracy, this performance is impressive compared to the state of the industry 20 years ago when horse hair hygrometers at ±10% RH were the norm and humidity was often considered a 'black art'.

So what makes humidity measurement so difficult?

2.1 Calibration

Calibrating relative humidity instruments accurately and efficiently is a daunting challenge. Quality and regulatory concerns, combined with recent technology advancements have led the industry to demand ever higher levels of relative humidity accuracy. With electronic relative humidity sensors boasting increased accuracies, huge strains have been put on the calibration systems which typically require three times better accuracy to calibrate them. Hence, relative humidity sensors are very dependent on accurate calibration in order to achieve their specified performance.

Calibration isn't just a matter of taking a humidity measurement and comparing it against a calibrated measurement. Instead, calibration requires the use of complicated and expensive reference standards which should be traceable, and accurate enough to support the intended accuracy of the calibration.

2.2 Measurement in Air

For relative humidity measurements, it is not necessary to measure the ambient temperature. However, to determine the dew point or absolute humidity, the ambient temperature is required. This can be a significant challenge, as air is a poor thermal conductor, and the temperature at any given point can be affected by thermal currents and temperature gradients, that make such conditions not only difficult to achieve, but time-consuming. It is very important to know and understand the dynamics of your system. Before taking a measurement, you always need to wait long enough to ensure that the temperature and humidity stabilize.

2.3 Wide Dynamic Range

Fortunately many relative humidity sensors actually respond in proportion to relative humidity and not in proportion to the amount of water vapour in the air. However, for many of these sensors the variation in the humidity sensor may only be a small proportion of the total dynamic range of the acquisition circuit. Sometimes a measurement parameter (e.g. sensor capacitance) may only vary by 1% to 10% for a full scale variation. In the case of a 2% change and an output resolution of 0.1%, the data acquisition system will need a resolution of 50,000 – which is 16-bit performance.

2.4 Temperature

Relative humidity is a very temperature dependent variable as discussed in application note "AN001 Understanding Humidity". Its value can change significantly with even slight variations in temperature and without any increase in water vapour. For example, a 1ºC error in the measurement of temperature at 35℃ and 75% relative humidity will introduce an error of ± 4% RH.

For the humidity sensors that actually respond in proportion to relative humidity and not absolute humidity, the issue of temperature measurement error isn't significant unless conversion to dew point, absolute humidity or any other measurement of water vapour in the air is required. In the case of a dew point calculation, a 1℃ error in the measurement of the temperature will produce approximately a 1℃ error in the calculation of the dew point.

This temperature dependency not only emphasizes the importance of excellent temperature acquisition, it also highlights the necessity of thermal stability, a condition that is often difficult to achieve. Because it is so difficult to maintain a stable temperature and humidity, it is best if the humidity measurement and the temperature measurement are taken as close as possible to each other – ideally on the same thermally isolated chip because even at short distances apart there can be considerable differences in levels of humidity and temperature.

3 UNDERSTANDING HUMIDITY SPECIFICATIONS

In order to select the best humidity sensor for a given application, it is important to understand the requirements of your application and analyze the specifications quoted in the datasheets. Datasheet specifications can hide a multitude of inaccuracies, and it can be difficult to compare specifications when different datasheets specify (or don't specify) the products differently.

The ideal sensor can and will change depending on the application, but, some or all of the following specifications and features are very important to understand before choosing your sensor.

3.1 Accuracy Specification

When looking at the accuracy specification it is important to understand how accuracy is specified.

Initial Specification

- Is this a typical or maximum specification? If it is a maximum specification, is it a maximum specification at 25°C only, or is it a maximum specification over the full temperature range?

Temperature Drift

- What is the temperature variation? Can the temperature be easily compensated for? What is the accuracy after temperature compensation?

Non-linearity

- Are non-linearities of the sensor included in the accuracy specification? Can these be compensated for? How accurate is the sensor after these non-linearities are compensated for?

3.2 Hysteresis

The output of a humidity sensor that includes hysteresis is not only dependent on the humidity, but also on the history of the humidity. What this means is that depending on whether the humidity is increasing or decreasing, the final settled value of the humidity measurement will not be the same.

If the humidity increases from 30% to 50%, the humidity sensor may eventually yield a reading of 50.0%RH. However, if the humidity was to decrease from 70% to 50%, the humidity sensor may eventually read 50.5% instead, resulting in a hysteresis of 0.5%.

- Is hysteresis specified? Is it included in the accuracy specification?

3.3 Noise / Repeatability

The output of the humidity sensor includes noise (sometimes referred to as repeatability), from both the data acquisition circuit and the humidity sensor. This noise is seen as flicker in the humidity reading even when the humidity is held constant.

Noise can be reduced by averaging, however this increases the response time and/or requires more measurements (per output) causing an increase in the power consumption required for each sample.

- Is noise specified? Is it included in the accuracy specification?

3.4 Interchangeability

A fully interchangeable sensor is one that can be replaced with a different part without requiring any recalibration or changes to the software. Some sensors have to be calibrated by the user and the calibration data is stored in the microcontroller software, hence it may be necessary to recalibrate after replacing a sensor. More modern sensors are fully factory calibrated and the calibration data is stored in the sensor itself, resulting in a fully interchangeable sensor.

3.5 Response time

A key specification in humidity measurement is the response time, which is a measure of how quickly the sensor responds to a large change in humidity. Fast response times are required for applications where sudden large changes in humidity can occur. However, fast responses are often achieved at the cost of accuracy. In most applications a fast response time is not critical because the humidity of an environment only changes slowly.

- What change in output is the response time specified for (this value can be 90%, 63%, 37%). How can you convert from one response time to another?
  - Note: For an exponential change a time constant is defined as the time to reach 63% of the final value (2 time constants = 86%, 3 time constants = 95% and 4 time constants = 98%).
- Is the response time measured in moving air or in still air? How fast is the air moving? How can these values be compared?
- Does the sensor respond to humidity changes even when the sensor is off?
  - For many sensors, the sensor element does not need to be powered on to respond to changes in the environment. This means that although the response time may be 10's of seconds or minutes, the sensor may still be powered up, take a measurement and power down again all within a fraction of a second and the humidity result will be valid.
- What is the recovery time after condensation settles on the sensor?

3.6 Long term stability / Immunity to contaminants

Many electronic humidity sensors have poor long term stability. Contaminants such as dust and vapors can alter the response of the sensor after exposure. Consequently, long term stability is dependent on the environmental conditions once the sensor is deployed, which is impossible to predict. Long term stability is often removed by periodic recalibrated.

- Is long term stability specified? Is it included in the accuracy specification?
- Does the long term drift slow down after one year or does the long term stability specification have to be added on for every year of use?
- What about immunity to contaminants? How do contaminants affect the sensor output?
- What contaminants is the sensor likely to encounter during normal operation?

3.7 Soldering / Storage and operational conditions

Some humidity sensors require very careful handling before and during manufacture, during transportation and storage and while operational. These specifications may limit the use of the humidity sensor and require a rehydration step. Therefore, it is important to understand the limitations of these specifications in your application.

- What humidity/temperature can the sensor be stored at before and after manufacture? What humidity/temperature can the sensor be operational at? How does this affect the long term stability?
- How can the part be soldered to the board – is this compatible with normal soldering process? Is any reconditioning after manufacture required?

3.8 Power Consumption

In order to calculate the power consumption of the humidity sensor, it is important to understand the power specifications and the power budget of the end application.

- What is the conversion current? What is the sleep current? What is the wakeup time?
- What is the application sample rate? What is the conversion time?
- Do I need to reduce the noise by averaging? What is my over-sampling ratio? How will this effect my power consumption?

4 ADVANTAGES OF USING CHIPSENSORS HUMIDITY SENSORS

The CS114 and CS124 are the first of ChipSensors family of digital relative humidity and temperature sensors. The CS114 integrates temperature and humidity sensor elements, an analog-to-digital converter, signal processing, calibration data, and an I^2C interface all in a single chip. Additionally, the CS124 includes a differential 12-bit auxiliary ADC for interfacing to an external light, pressure, or bridge sensor.

The CS114 and CS124 offer low power, high accuracy, and stable calibrated solutions making them ideal for applications ranging from automotive, industrial HVAC systems to environmental sensors and cost sensitive remote data-logging applications.

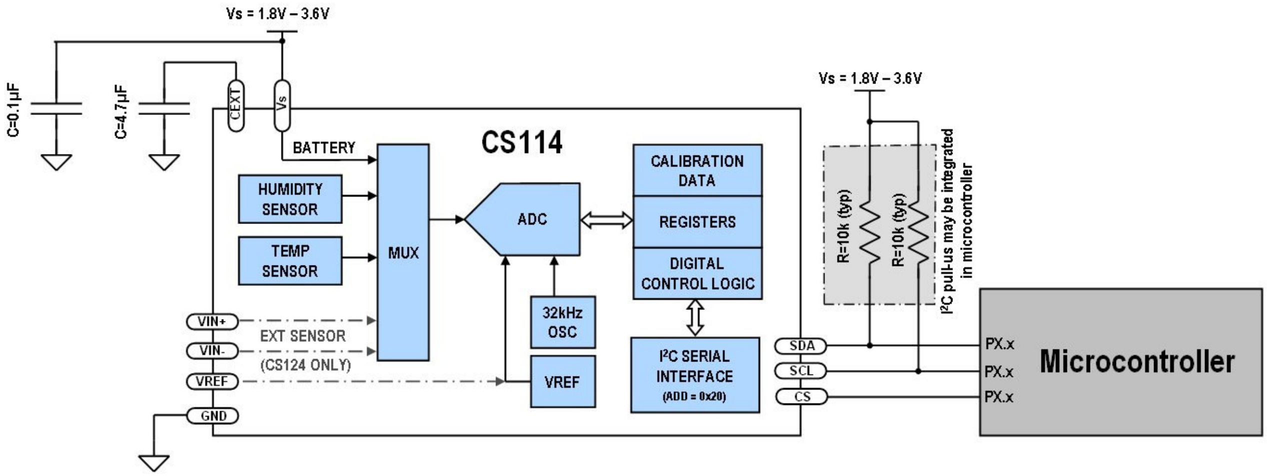

Figure 1 – Application example of the CS114 (or CS124).

The features and benefits of ChipSensors humidity sensors make them the ideal choice for most applications as outlined below:

4.1 Excellent Accuracy

ChipSensors humidity sensors offer excellent accuracy specifications. The CS114 and CS124 offer accuracy specification of ±2.0%.ChipSensors patent-pending use of low-K dielectrics and proprietary sensing structures mean that the sensor is much more immune to the following additional error sources:

- **Hysteresis** has been significantly reduced by design.
- **Long Term stability** is greatly improved.
- **Immunity to contaminants** is greatly improved.

4.2 Factory Calibrated – Fully Interchangeable

The CS114 and CS124 are individually factory calibrated for both temperature and humidity, with the calibration data stored in on-chip OTP (One time programmable memory). Hence, no further calibration is required to achieve the specifications listed in the datasheet. The CS114 and CS124 offer excellent long term stability, and can be designed into an application without requiring further calibration. Furthermore, since the calibration data is contained within the chip, the sensors are fully interchangeable.

4.3 Long term stability, Immunity to Contaminants, Soldering, Storage and Operational Conditions

ChipSensors use of propriety sensing structures ensures excellent:

Long Term Stability

- The ChipSensors range of humidity sensors, are specifically designed to ensure long term stability.

Immunity to Contaminants

- Absorption of contaminants into the sensor structure can change the electrical characteristics of the sensing material. ChipSensors propriety sensing structures ensures that the sensors can operate in even the most challenging environments.

Soldering

- Many humidity sensors have issues with the high temperature associated by soldering.

  The CS114 and CS124 can be soldered by hand or using wave soldering. Standard guidelines apply. Rehydration is not required.

Recovery from Condensation

- Some humidity sensors can be damaged, or can take a very long time to fully recover from condensation. The unique sensor structure of the CS114 and CS124 means that once condensation has been removed, the sensor will quickly recover. The sensor is not damaged by water immersion or condensation.

4.4 Integrated Temperature sensor

The CS114 and CS124 both include an internal temperature sensor. The temperature sensor is connected directly to the Paddle underneath the IC and should be thermally isolated so that the CS114 and CS124 can both reach thermal equilibrium with the environment around them and not being heated by other ICs on the PCB. Please refer to the CS114 demo board PCB guide for more details.

The temperature measurement can be used to calculate other humidity related measurements from the relative humidity measurement: e.g. Dew point, absolute humidity, wet bulb temperature, water vapour pressure etc.

4.5 Auxiliary ADC

The CS124 includes an auxiliary ADC. While this ADC can be used for any voltage measurement, it is targeted at external sensors including light, pressure and bridge measurements. Please refer to the datasheet for specifications.

4.6 Digital Output

Measurement data in a digital format means that additional processing and communication of data is simplified. Furthermore, additional data acquisition circuitry is not required. The specifications given in the datasheet are the actual specifications of the full humidity measurement and include the inaccuracy of the acquisition system. The user does not have to design a data acquisition circuit (saving cost) or calculate the added noise, drift and inaccuracies added by the acquisition system.

4.7 Power Consumption

The CS114 and CS124 are low power devices suitable for battery applications. The conversion time and noise performance of the sensor measurement can be traded off for the particular application. While the default conversion time is 300ms, for power sensitive applications reducing the conversion time to 47ms will reduce the power consumption per conversion. For a more detailed discussion on achieving low power performance, please refer to technical note “AN003 – Using the CS114 or CS124 in battery powered applications”.

4.8 Small size, low cost, Excellent Manufacturability

Other factors which will affect the choice of humidity sensor are as follows:.

Small Size

- The CS114 and CS124 are packaged in a tiny 4mm x 4mm QFN package. This package is small enough to fit on probes. Please contact info@chipsensors.com to discuss other packaging options.

Low Cost

- The CS114 and CS124 are low cost humidity sensors. Please contact info@chipsensors.com for details.

Excellent Manufacturability

- The CS114 and CS124 are manufactured using standard CMOS processes. This has the advantage that production quantities can be ramped up into very large volumes as required.