# Evaluating MEMS, ASIC chips for automotive apps

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AEC-Q100 does not address MEMS and unencapsulated devices. This is where the engineer designing the test plan must get creative in seeking a solid physics-of-failure-based test regime.

This article describes the technical challenges related to automotive electronics qualification and verification of a MEMS-based sensor and ASIC system. The example device is an SoC, fully calibrated, surface mount IC, which comes in one of three humidity outputs, digital, ratiometric or linear (0-1V).

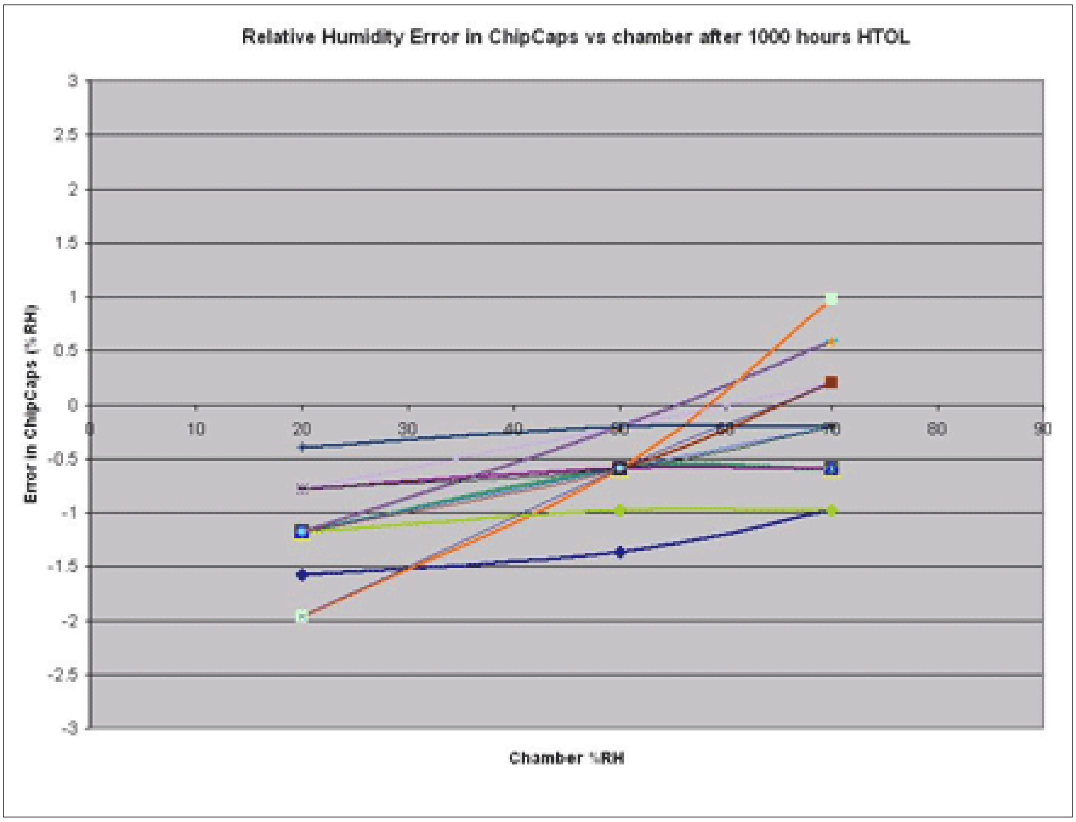


Figure 2: Shown is the relative humidity error in ChipCaps vs. chamber after 1,000hrs HTOL.

Testing results presented will focus on application of the following tests:

- Temperature-humidity bias life;
- Temperature cycling;
- High-temperature operating life;
- Early-life failure rate;
- ESD Human Body Model;
- ESD Charged Device Model;
- Latch-up;
- Characterization;
- Solderability;
- Electrical transients;
- Wire bond pull testing (both encapsulated and unencapsulated).

This feature shows how to adapt industry standard tests to a non-standard device, resulting in an assessment of the robustness of a MEMS-based sensor system.

Topics covered include: criteria for evaluating the quality and reliability of a MEMS-based temperature and humidity sensor to ensure reliable performance in automotive applications; assessment of electrical and environmental tests and requirements as they apply to dual silicon temperature and humidity devices; and review of MEMS system qualification results, reliability assessments and test results.

The first natural step in designing the qualification plan for MEMS-based sensor and ASIC chip systems would be to review AEC-Q100 for the traditional automotive requirements. AEC-Q100 or "Stress Test Qualification for Integrated Circuits" is maintained by the Component Technical Committee of the Automotive Electronics Council (AEC). However, it's clear that AEC-Q100 does not have specific requirements for MEMS devices and does not address unencapsulated devices. This is where the engineer designing the test plan must get creative in seeking a solid physics of failure-based test regime.

## Circuit function

The ChipCap series humidity sensor by GE offers a new standard in the field of accurate relative humidity measurement. Based on a capacitive polymer sensing technology, this device offers signal conditioning and temperature compensation for a single SoC device. Its measurement capability is accurate to ±2 percent from 20 percent to 80 percent relative humidity (RH) and ±3 percent across the entire humidity range at 25°C. The temperature accuracy is ±1°C from 0°C to 70°C. ChipCap provides either analog or digital interfaces in a single, 5VDC-powered chip. Dual outputs furnish humidity and temperature as linear (0-1V),

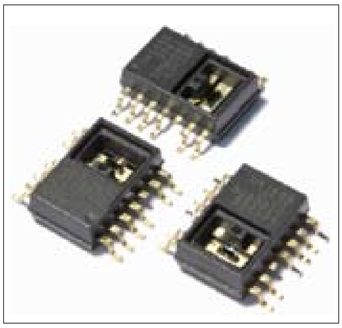

Figure 1: ChipCap relative humidity sensors change capacitance in direct proportion to ambient relative humidity.

ratiometric (10-90% of VDD) or with digital output (ZACwire one-wire interface).

ChipCap relative humidity sensors change capacitance in direct proportion to ambient relative humidity. An internal solid state band gap provides the temperature output measurement. The ChipCap 14-pin SOIC-packaged MEMS sensor and ASIC is shown in Figure 1.

Its device specifications are as follows:

- Relative humidity
  RH sensor: Planar capacitive polymer
  RH range: 0 to 100% RH
  RH accuracy @ 25°C: ±2% from 20 to 80%; ±3% from 0 to 20% and 80 to 100%
  RH resolution: 0.4% RH

- Temperature
  Temperature sensor: Integral band gap PTAT
  Temperature scale: -55°C to 150°C
  Temperature accuracy: ±0.6°C at 25°C
  Temperature resolution: 0.2°C

- Environmental
  Storage temperature: -55°C to 150°C
  Operating temperature: -40°C to 85°C
  Operating RH range: 0 to 100% RH, non-condensing

The review of temperature humidity bias (THB) life test was the most critical test for this device. The ability of the encapsulated ASIC to survive THB was never in question. The use of modern Pb-free "green" epoxy molding compounds designed to handle automotive temperature extremes assured our success. However, based on 25°C testing results by our sensor supplier, we needed to prove that the exposed humidity sensor could survive a lifetime of humidity-temperature and bias. This test is particularly severe for the sensor and its exposed wire bonds.

For this evaluation, we selected THB of 85°C/85% RH for 1,000hrs with voltage bias applied. The DUTs were interrogated weekly for both temperature and humidity output. Standard JEDEC 22 preconditioning or simulated reflow soldering and other typical manufacturing stresses were performed prior to THB and thermal cycling.

In fact, at one point in the qualification, our test lab—following the JEDEC specification to the letter—submerged the DUT board in liquid flux. The chlorine-based flux system caused a drift in the humidity output, but did not cause a failure of the sensing die. After this "mistake," we only allowed deionized (DI) water to be used to clean the part. The sensor die is not damaged by DI water, and short exposure to hazardous chemicals will not damage the sensor (perhaps only shifting the reading).

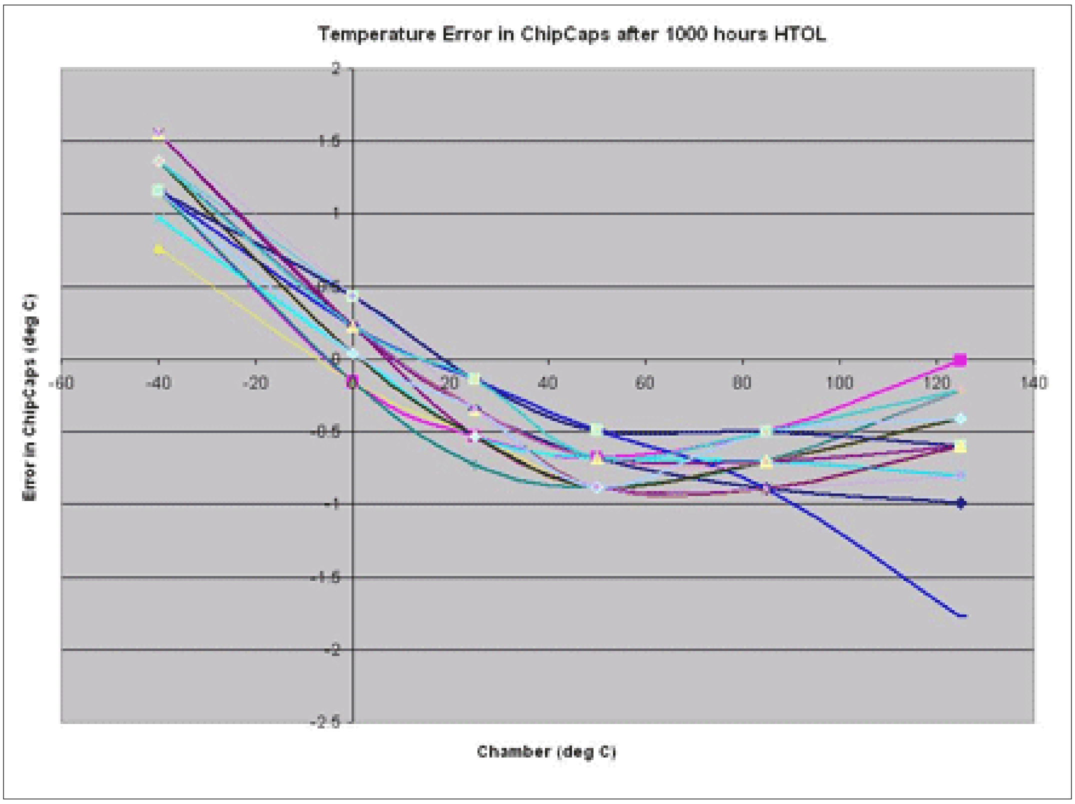


Figure 3: Shown is the temperature error in ChipCaps after 1,000hrs HTOL.

These types of humidity sensors are known to shift less than 1 percent RH in reading when exposed to isopropyl alcohol, hydrogen peroxide and sodium hypochlorite. Longer term or high concentration exposure to chemicals like ammonia hydroxide and acetone may cause a failure of the sensor. It is recommended that the design engineer carefully assess the potential for chemical exposure before finalizing the design using the ChipCap.

Another critical test for reliability for the ChipCap is the high-temperature operating-life and early-life failure rate tests. These tests were run at 85°C for 1,000hrs and at 85°C for 160hrs, respectively. Results of this testing indicate a calculated mean time between failure (MTBF) of 3.6 operating million hours.

Additionally, electrical overstress tests selected were ESD human body model (HBM), charged device model (CDM) and latch-up. The test for HBM was ±2kV per pin and for CDM, it was ±500V all pins and ±750V for all corner pins. Despite the size of the IC package (thicker SO-14), the device passes the ESD CDM test easily. Perhaps the "open cavity" design with less bulk plastic reduces the package charge buildup.

The latch-up test is performed with injection of ±100mA into each pin. The key for this test is that one must run the device at its maximum operating temperature to ensure the highest probability of activating any latent latching silicon control rectifier structures in the silicon and substrate regions. This is another key test for design validation to ensure that destructive latching or stuck-at-faults do not occur for our customer's application.

**Transient testing**

Also critical for automotive applications is the running of electrical transient testing. Voltage drops, droops and peaks are all part of life in an automotive electronics system. We evaluated the ChipCap to a random spike test using an arbitrary waveform generator. Additionally, repetitive testing of power and ground interruption completed the transient testing. Once again testing at elevated temperatures was vital to this evaluation.

To verify for mismatch of thermal coefficients of expansion and delamination of the sensor, ChipCap was evaluated using the thermal cycling test from -40°C to +125°C for 1,000 cycles. Afterwards, both the ASIC and humidity sensor bond wire needed to undergo the wire bond pull test. The 3g pull-strength requirement (for encapsulated wires) was used. All wires pulled at over three times the force requirement.

Solderability testing of the ChipCap used the "dip & look" Pb-free JEDEC 22 method. Occasionally the alternate method "solder reflow" is used when the "dip & look" result indicates failure or the results are not conclusive. "Dip & look" is the method of choice, but the more costly "solder reflow" method leads to more accurate results.

Characterization, according to AEC-Q003 Guideline for Characterization of Integrated Circuits, is the process of determining the fundamental electrical and physical characteristics of a device based on statistical analysis of experimental data or modeling. The critical factors for characterization of ChipCap were stability and accuracy of the measurement equipment including the reference standards.

The measurement of humidity and temperature benefits from test chamber uniformity, elimination of thermal gradients and enhanced repeatability. For ChipCap, we found we needed a humidity chamber accurate to ±1 percent RH over the range of 20 percent to 90 percent RH. For temperature, the goal for test equipment accuracy was a ±0.1°C over the range of -40°C to +85°C.

The reliability assessment of the ASIC is fairly straightforward with the MEMS sensor being somewhat more complicated. For automotive applications, we need to consider the mission profile or the intended use of the sensor device. Certainly we will prepare a different qualification plan for a device used "under the hood" than for "cabin comfort."

For the purposes of this review, let's consider the main use of the ChipCap as cabin comfort; in other words, the use of its temperature and humidity outputs to regulate and control the environment within the passenger compartment in the vehicle. It is not difficult to imagine the many uses of this device within the controlled area of the passenger compartment. By understanding the mission profile, we can better understand the end application, and the customer's needs for robustness and reliability.

With a total operating life of 20,000hrs, the following would be a typical mission profile for this application:

- 16,000hrs at an average ambient temperature of 30°C;
- 4,000hrs at an average ambient temperature of 55°C;
- 1,000 thermal cycles of 20°C to 55°C;
- 600 thermal cycles of -10°C to +30°C.

The rated operating temperature range of the ChipCap ended up being -40°C to 85°C considering its end use. The storage temperature range is -55°C to 150°C.

It is important to note that key mission profile information should "drive" the selection of qualification testing. In this example, with the result of the qualification for thermal cycling life test, we can calculate the MTBF for the ChipCap. The following calculation is based on the use of the inverse power law (typically applied to metal fatigue). The testing of 93 ChipCaps for 1,000 thermal cycles (-40°C to 125°C) with zero failures (chi squared factor of 4.605) results in a mean cycles between failure of 22 million cycles. MTBF can be derived after considering the typical end use cycle in hours.

**Test results**

Here is one example of the qualification test results. Refer to Figures 2 and 3 for the error for humidity (upper curves) and temperature (lower curves), after the 1,000hr high-temperature operating life test. The upper plot shows the final readings with an error within ±2 percent RH over the range of 20 percent to 70 percent RH.

After 1,000hrs at 85°C, the ChipCap stayed within ±2°C over the temperature range of -40°C to 120°C. There was no significant change or shift in the temperature curves after the life test.

This article demonstrated the thought process for evaluating the quality and reliability of a MEMS-based temperature and humidity sensor IC to ensure reliable performance in automotive applications. Also discussed were the assessment of electrical and environmental tests and requirements, and a review of MEMS system qualification requirements, reliability assessment and test results.

Through careful selection of testing, one can adequately evaluate MEMS-based sensor and ASIC chip systems for automotive applications. A successfully designed and implemented qualification plan is one sure way of assuring a positive result for your production parts approval process (PPAP) submissions.