Unit for Investigation of the Working Environment for Electronics in Harsh Environments, ESU

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Abstract When electronic equipment is used in harsh environments with long expected lifetime, there is a need to understand that environment more in detail. This situation is today a reality for many application areas including the automotive sector, heavy industry, the defense sector, and more. To fully understand the working environment, a unit has been developed to monitor physical data such as temperature, vibration, humidity, condensation, etc., to be used in the product development phase for new products. This paper presents the underlying principles for the ESU (Environmental Supervision Unit) and details on the design.

Keywords Harsh environment · Monitoring unit · HALT · Condensation sensor · Multi sensor unit · Reliability

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1 Introduction

The basic idea behind the project is to provide the industry with a unit for monitoring the environment for the customers' electronics units during the development phase and/or during actual use. This ESU (Environmental Supervision Unit) can be configured in many different ways using transducers for different physical parameters. The rationale for this is that in order to design electronics equipment that needs to be reliable in harsh environment, there is a need to understand this environment in detail.

Reliability of an electronic product is normally assured by designing, manufacturing, and testing them according to standards. These standards are based on best practice of mature technologies and the main focus is to assure good manufacturing quality. However, new types of components such as QFN and fine-pitch BGA components may have inadequate solder joint life even if they have been produced with perfect manufacturing quality. This is mainly a problem for high reliability products that are expected to have a long life in harsh conditions. The main factors affecting the life of solder joints are thermomechanical stress due to temperature variations and mechanical stress due to vibration or shock. Therefore, in order to assess the life of solder joints it is necessary to have information of the stresses solder joints will be exposed to during the whole life of the product, not only during service but also during handling and storage. It is not only the maximum and minimum temperatures and the maximum vibration levels that need to be determined. The number of temperature cycles with different delta temperature and the variation in vibration levels must be known in order to facilitate assessment of the life of the solder joints.

In addition, condensation of water on the board of electronic equipments is a well-known cause of failures.

In an ongoing Swedish national project, "Requirements specification and verification of environmental protection and life of solder joints to components", the ESU will be used for characterizing the actual field environment for a number of products used in harsh environments. This will give information of the usefulness of the ESU. The project is supported by the Swedish Governmental Agency for Innovation Systems (VINNOVA).

2 Monitoring Unit, ESU

The SME Setek Elektronik AB located in Gothenburg, Sweden, is currently investigating the market potential for the ESU and will build a number of prototypes to be evaluated by an industrial reference group. This group consists of vehicle manufacturers, (cars, trucks, trains, boats, etc.) in the project "Requirements specification and verification of environmental protection and life of solder joints to components" mentioned earlier.

The transducers for the current version of the ESU is equipped with

- Condensation sensor provided by CiS. (A unique sensor on the market)
- Several sensors for temperature. (Commercial)
- Sensor for relative humidity. (Commercial)
- Sensor for vibration, acceleration, and displacement. (Commercial)
- A large memory for storing environmental data for long times

Figure 1 shows the current design and Fig. 2 shows that particular sensor. A more detailed layout of the sensor chip is shown in Fig. 3.

The basic functionality of the condensation sensor is: Condensation leads to the formation of droplet of the sensor surface. The detection of droplet bases on the capacitive principle using an electric stray field on a dense surface. The principle is shown in Fig. 4. The packaging withstands the corrosive properties of condensate over many years. The upper passivation layer consists of silicon nitride, is mechanical stable, and allows a cleaning if necessary. It enables the detection of droplets as small as some µm on the sensor surface. The overall impedance of the stray field capacity shows a marked frequency response, which is greatly dependent

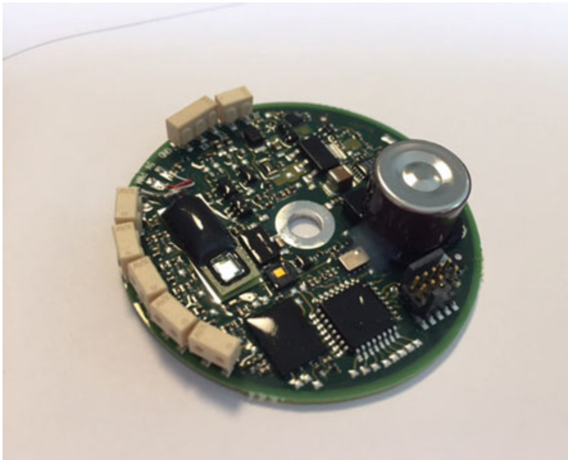

Fig. 1 Picture of the prototype

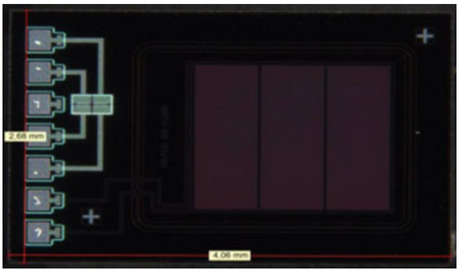

Fig. 2 Picture of the unique condensation sensor

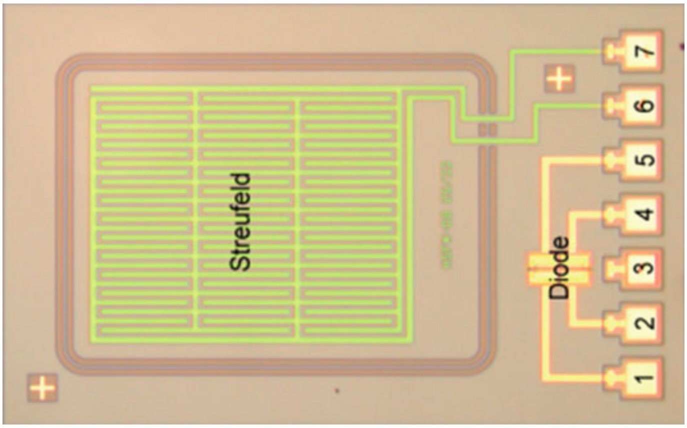

Fig. 3 Layout of the condensation sensor chip

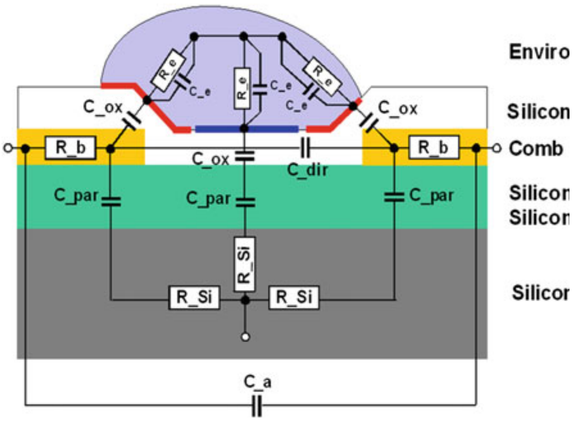

Fig. 4 Measurement principle of the condensation sensor

in its course on the properties of the surrounding medium. Figure 5 shows a typical packaged condensation sensor.

If necessary, the extent of the condensation can be given quantitatively (Fig. 6). This requires that the sensor is calibrated.

A capacity frequency converter allows the transportation of the signal via a longer distance. In principle, the method is also appropriate to give information on impurities [1]. The sensor also includes a diode for measuring the temperature which allows detecting the condensation and temperature at the same place. Figure 7 shows the characteristics of seven different temperature diodes of one type.

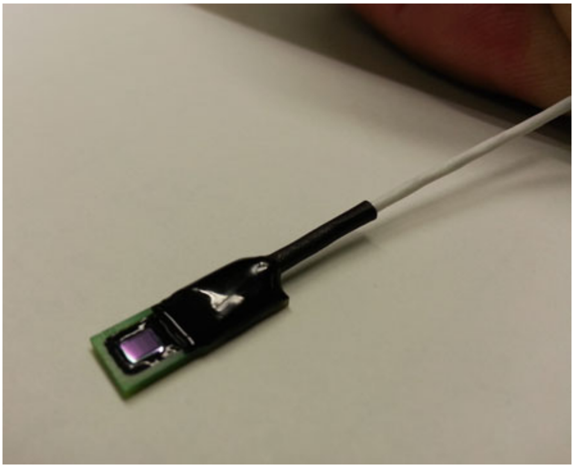

Fig. 5 Packaging of the condensation sensor

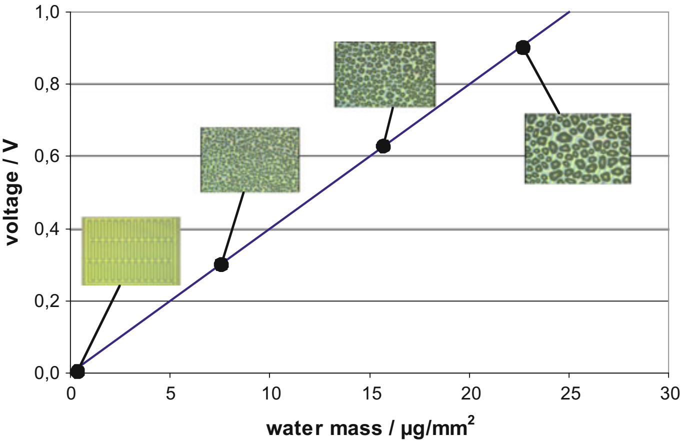

Fig. 6 Correlation of droplet size and signal

The condensation sensor is mounted on a tinned pad on the ESU with a thermally conductive epoxy (Fig. 8). The pad is connected to the underside of the ESU FR4-card by thermal vias to increase the heat flow from the mounting surface to the sensor.

The ESU can be mounted to any surface either by a screw through the hole in the middle of the device or by a differential tape. The adhesion is strongest on the ESU side of the tape which facilitates removal or relocation of the ESU by not leaving any residues on the mounting surface. The tape can easily be replaced by a new one upon removal of the ESU.

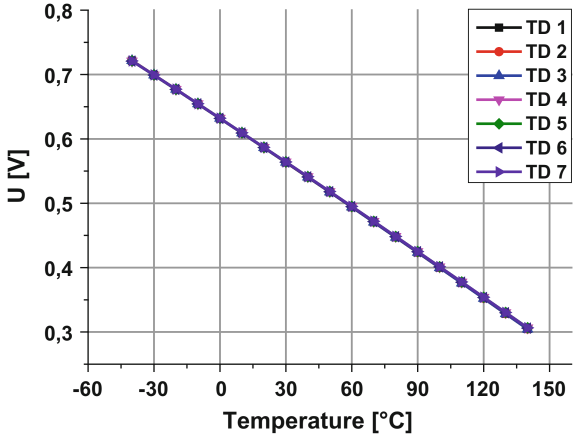

Fig. 7 Voltage–temperature characteristics of seven different temperature diodes of one type

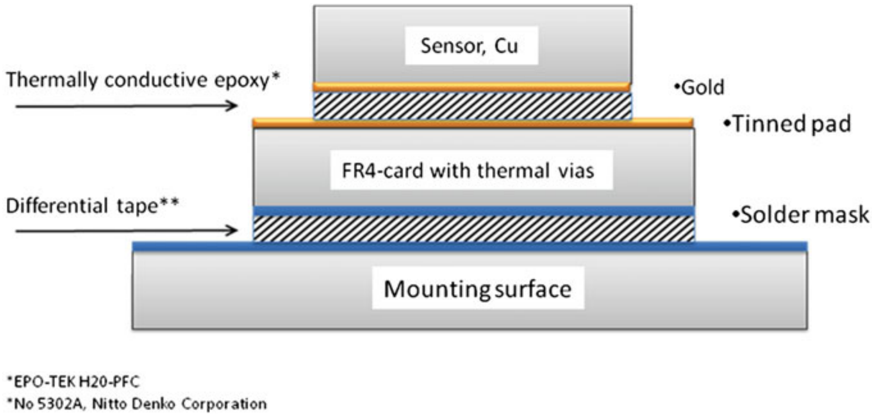

Fig. 8 Mounting of the condensation sensor and the ESU in an application

Since the ESU will be monitoring harsh environments the prototype will need to function in that environment.

The design specifications in short for the unit are

- Temperature range: -40 – +125 °C
- Temperature ramp: 60 °K/min
- Current consumption: as low as practical, few mA at 12 V.
- Supply voltage range: 7–36 V DC
- Vibration level: maximum 65 G RMS.

It should be observed that some of these requirements are operational and some are based on survival of the unit. We can, for instance, not measure vibration levels up to 65 G RMS with the current accelerometer but the sensor survive that level without damage.

2.1 ESU Main Data

The main data for the ESU in the current configuration are

- Diameter: 46 mm.
- Height: 12 mm
- Weight: 10 g
- Processor ARM Cortex M0+ from NXP.
- 256 M bit NOR flash
- Minimum 100,000 ERASE cycles per sector
- More than 20 years data retention
- Current consumption while measuring: 12–13 mA typical @13.6 V

It should be emphasized that the ESU can be configured in a modular way with additional sensor types that a customer should require. Also, times between measurement samples, recording times for each measurement, etc., are relatively simple to adjust in the software of the unit.

2.1.1 Condensation Measurement

The condensation sensor measures micro-condensation and presents the result as volume precipitated water per surface unit.

One new sample is taken every 100 ms.

To have a reliable analogue value requires manual calibration of each individual sensor. The measurement in the ESU is therefore "digital" and will just detect condensation or no condensation. The sensor will trig when condensation drops are approximately 3–4 m or larger.

The sensor element should as far as possible be protected from contamination.

It is very important that the sensor has the same temperature as the test surface.

The condensation sensor is normally glued to the ESU but as an option it can be delivered mounted on a cable at a distance of up to 90 cm (or longer). If this option is selected, one of the external temperature sensors must be placed close to the condensation sensor.

2.1.2 Relative Humidity Measurement

Relative humidity is measured using a commercially available sensor with the following data:

- Relative Humidity Accuracy ± 2% (typical)
- Integrated temperature accuracy ± 0.2 °C (typical)
- 14 Bit Measurement Resolution
- One new sample taken every 100 ms.

2.1.3 Vibration Measurement

A commercially available accelerometer is used for measuring vibrations.

- 3 axis measurement
- ±16 G range
- 13-bit resolution
- Max data output rate = 3200 Hz - > Max bandwidth = 1600 Hz. Not fully utilized at this time.

One measurement value for each axis is produced for every sample.

It is important that the ESU is firmly connected to the test object to get reliable acceleration values especially if frequencies are high.

One new sample taken every 1 ms. The maximum value measured during the selected sample time is stored during log. A more sophisticated calculation could be used in future.

2.1.4 Temperature Measurement

Up to five NTC temperature sensors can be connected to the ESU and placed at different spots on the test object. There is also a sensor placed close to the condensation sensor on the ESU.

- Temperature range: −55 to 155 °C
- Inaccuracy: TBD

New samples are taken every 100 ms.

2.1.5 RTC

A real-time clock is integrated to the ESU to be able to time tag each measurement record.

A super capacitor is used to supply the RTC when normal supply is removed.

- Clock inaccuracy: ± 10 ppm (typical)
- Time tick: 1 s
- Max run time without supply: TBD

The real-time clock is important since often there is a need to back track when a particular event happened, like when condensation occurred. The real-time clock provides a mean for synchronizing data from the ESU to other measurements done in the evaluation of a product.

2.1.6 User Interface

A standard asynchronous serial connection (UART) is used to give commands to the ESU and to read out data. Any terminal program with logging capability could be used.

Data is sent out on the serial port in a CSV (Comma Separated Values) format which can easily be loaded into Excel and other programs.

2.2 Reliability of the ESU

The unit has been tested using HALT (highly accelerated life testing) which is a stress test used to quickly find defects and weaknesses related to the product design, manufacturing processes, and material selection of the product. During the HALT, stresses are applied to the unit by step-wise increasing levels of vibration and/or temperature outside the p roduct specification in order to cause failures in short time. When failures are found, proper actions can be taken to increase the products reliability.

The halt consists of four parts; *Thermal Step Stress Test*, During which the ESU was tested between −90 and 125 °C, *Rapid Thermal Transition Test* where the unit is exposed to rapid thermal chocks between −40 and 125 °C with a ramp of at least 60 °C/min, *Vibration Step Stress Test* where the ESU was subjected to omni-axial random vibrations up to 65 G_{rms} and a *Combined Environments Test* where the *Rapid Thermal Chock* test is combined with vibrations up to 65 G_{rms}.

Findings from the HALT showed that the ESU had a robust design but with potential for improvements of the reliability by stabilizing its Super Capacitor mechanically. Later editions of the ESU have been ruggedized by gluing the Super Capacitor to the PCB.

2.3 EMC Test

The emission of the ESU was tested using standard test equipment in the EMC-lab of Swerea IFV. Since there is a broad application area, the unit was tested applying the limits for household applications from CISPR 32 which are the tougher requirements. The unit passed these tests.

Depending on the actual working environment of the unit, there could be requirements to test the unit also according to CISPR 25 with the adoptions to that standard following the different companies' interpretations. This would require a different setup of the test equipment. It is foreseeable that these tests will be crucial for different fields of application.

Immunity to electromagnetic fields and pulses has not been tested at this stage. Here, the required tests will also be determined by the actual working environment according to the end users' needs.

3 Market Assessments

The first batch of prototypes was delivered to an industrial reference group for evaluation in the spring 2017. This group consists mainly of companies in the automotive sector in Sweden. One initial result was that the configuration of the unit had to be adapted to suit each customer regarding what sensors where of interest and details in the software and how the results should be gathered. First results from the field tests are expected early autumn.

The ESU was also presented on a trade show in Gothenburg in March 2017 and gained some interest among companies in business sectors not initially foreseen. These applications were in ventilation systems for buildings and general environmental monitoring in housing regarding for instance condensation. For the SME, Setek Elektronik AB these applications were the first commercial successes for the unit.

The ESU will also be used in a national research project regarding monitoring of the environment for fresh water plants in Sweden.

Apart from the industrial reference group, the SME also works on marketing of the ESU towards the defense industry. In Sweden the organization FMV (Swedish Defence Material Administration) is of interest.

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Reference

Westenthanner M, Barthel A, He P, Beckmann D, Steinke A, Tobehn I, Frank T., Pliquett U (2013) Assessment of suspension medium conductivity by means of micro electrodes. J Phys Conf Series 434. article id. 012093

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