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AS RELIABLE AS THE SUN

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I. INTRODUCTION

Fortunately there is almost nothing as reliable as the sun which can consequently be utilized as a very reliable source of spacecraft power. In order to harvest this power, the solar panels have to be pointed towards the sun as accurately and reliably as possible. To this extend, sunsensors are available on almost every satellite to support vital sun-pointing capability throughout the mission, even in the deployment and save mode phases of the satellites life. Given the criticality of the application one would expect that after more than 50 years of sun sensor utilisation, such sensors would be fully matured and optimised. In actual fact though, the majority of sunsensors employed are still coarse sunsensors which have a proven extreme reliability but present major issues regarding albedo sensitivity and pointing accuracy.

Lens R&D is designing and producing some new generation sunsensors which are all characterized by a very high reliability and which present advantages in the field of operating temperature range, accuracy, costs or a combination of these parameters.

this paper will focus on results achieved during the first two years of development and provides a peek into the future of sun-sensing with several new developments that are under consideration. All of these developments have the same goal though; preferably the reliability of the sensors shall only be surpassed by the reliability of the sun itself.

II. Reliability driven design.

Reliability cannot be captured by a single parameter but is affected by many parameters related to very divers subjects ranging from base materials used, through interconnect reliability, avoiding human errors and increasing repeatability during manufacturing. A reliability driven design will take all these issues into account and will try to optimise size, costs, functionality, reliability and other parameters with reliability as one of the most important parameters.

In order to be able to optimize the reliability of a design it is necessary to have some insight into which items are important for the reliability and how these parameters also affect the required functionality of your product. In this paper some of these issues will be discussed, taking the design of a sunsensor as the basis.

There are several type of sunsensors used on satellites, ranging from single photodiodes (coarse sunsensors) through multiple arrangements of single photo diodes and other analogue fine sunsensors to digital or quasi digital sunsensors.

A single photodiode can be used as a sunsensor by looking at the current generated and as such it is the simplest sunsensor available. These sunsensors are not very accurate in determining the incident angle of the sunlight (5 to 10 degrees). But they only have a limited number of connections, and to make them reliable the main emphasis is on the mechanical and electrical interconnects. Selecting the right housing and isolation materials and adhesives to provide the required mechanical interconnects is relatively straight forward and will allow the sensors to sustain many large temperature variations without mechanical failure. This however leaves the electrical interconnect as the main source of worries.

From reliability point of view there are various methods for electrical interconnect available which show different properties.

- Soldered connections are easy to make but show generally poor reliability as compared to other methods
- Brazed connections (high temperature soldering) are fairly easy to produce but require temperatures which are too high for interconnecting electronic parts.
- Glued connections are more difficult to make, have less heritage are less used but tend to show a higher reliability under extreme conditions than soldered connections
- Direct metal to metal contacts like welded connections, crimped connections or wirebonds are significantly more difficult to produce but exhibit by far the highest reliability.

Despite the fact that soldered connections are brittle, only qualified over a limited temperature range and not resilient to mechanical stress, this method is still used for the majority of interconnects mainly because of the ease of manufacturing, quality inspections and the high level of heritage. Especially in the field of electronics board's production, soldering will allow to make many connections at the same time under similar circumstances by using reflow soldering systems. Soldered interconnects however are not seldom a cause of failure especially when not enough stress relieve is provided.

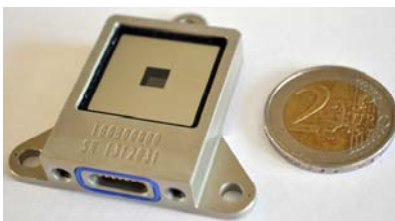
Electrically conductive adhesives are often used for instance to provide a backside contact to electrical chips and seldom cause failures. Furthermore thermal cycling on sunsensors where the wires were glued instead of soldered have shown a better resistance to thermal cycling than soldered connections. Despite this, glued connections are seldom used when connecting wires within electronic components or systems. It is believed that this is due to the fact that there is not much heritage (leading to a certain level of anxiety) and no clear accept and reject criteria like those for soldered connections, welds or wire bonds.

Welding, crimping and wirebonding are all techniques to make a direct metal to metal contact through the deformation of the mating interface. As there will be no (or very limited) differences in coefficient of thermal expansion (CTE) of the joining materials involved, these connections tend to have a very wide operating temperature range and high resilience to thermal cycling. For this reason welded connections are generally used for connecting solar cells and wire bonds (as used inside many electronic packages) are considered the most reliable interconnect methods available.

Despite the fact that all coarse sunsensors use a single or multiple single photodiodes, there are still significant differences in reliability to be found which are generally caused by the base materials selected (a silicon diode mounted on a ceramic substrate is most probably more reliable than one mounted on an FR4 printed circuit board) and the method of interconnect used. As no amount of process control can compensate for a bad material or interconnect system selection, this will have to be taken into account from the start and are some of the most important reliability determining parameters.

The selection of the materials to be used becomes more complicated as soon as one starts looking at fine sunsensors. This type of sensor is typically build-up of multiple photodiodes being illuminated through an aperture in some opaque material. As a consequence next to a diode and carrier, additional components will need to be considered which will generally be produced from different base materials with different CTE's. Typical material combinations for this type of sensors are Kovar and glass or titanium and sapphire as for these materials the differences in CTE are small, allowing for a large temperature range. Life however is not that simple and there is more to say about material choices.

As sunsensors are directly facing the sun during operation (which will input $136\text{mW}/\text{cm}^2$), one should take a significant heat input into account which will increase proportional to an increasing surface of the sensor. In order to get rid of the absorbed heat, materials with a high thermal conductivity are advantageous (like aluminium). Next to this, many satellites have magnetic cleanliness requirements and Kovar is a ferric system which may or may not cause requirements to be superseded so this will always need to be checked. Titanium is a material which is difficult to process leading to more expensive parts (as more exotic manufacturing methods or tools need to be selected) Next to this Titanium has a significantly worse thermal conductivity than aluminium. In any event, both Kovar and Titanium have in common that they are much more difficult to process, less commonly used and therefore significantly more expensive.



BiSon 64 space grade sunsensor

III. BiSon 64 sunsensor development

Different material systems lead to a situation where different implementation will have advantages in one situation and disadvantages in the other and no one type fits all situation can be created. One can however design sensors which fit as many missions as possible. This is why the BiSon 64 sunsensors use an aluminium housing sapphire window and PEEK insert, to provide the best possible combination of thermal conductivity and costs. The comparatively large CTE difference between Aluminium and Sapphire will limit the operating temperature though. Furthermore the PEEK insert will render application at temperatures below some -40 degrees C less favoured.

This is why a new version of the BiSon 64 is under development (the BiSon64-ET) which will have a titanium housing and an Al₂O₃ insert. In combination with wirebonding of the interconnects and a conductive glue to make the backside contact for the photodiodes it is expected that this sensor will show the capability of being operated in a temperature range ranging from liquid nitrogen (-196 degrees C) to at least +125 degrees C, thus covering all known applications of sunsensors, ranging from direct solar panel mounting to extra-terrestrial rovers.

As the BiSon sunsensors in general are characterised by a low building height and minimum exposure of the housing material to direct sun input (the majority of exposed area is covered by the sapphire window which is coated with a high quality aluminium coating, thus reflecting most of the heat input back to deep space) thermal control of the sensors is expected to be relatively simple as compared to other sunsensors.

Due to the material system and interconnect methods selected, it is expected that the reliability of these sensors is only surpassed by the sun itself.

- [1] <http://en.wikipedia.org/wiki/Albedo>
- [2] P.Fidanzaty et al, Miniature sunsensor on a chip optimization, ESA GNC conference, 2011 Karlovy Vary.
- [3] C.W. de Boom et al, Flight experience of TNO sunsensors, ESA GNC conference 2011 Karlovy Vary,
- [4] C.W.de Boom et al, Mini-DSS : Miniaturized High-Precision Sun-Angle Measurement", ESA GNC Karlovy Vary,
- [5] J.Leijtens, From space to Earth and back (sunsensors on a detour), ESA GNC conference 2014 Porto.