ON HOW OUR BLUE MARBLE CAN RUIN YOUR SUN ATTITUDE MEASUREMENTS

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ABSTRACT

Lens R&D is well known for their high reliability Sunsensors and ISISpace is well known for their reliable CubeSats, so it should come as no surprise that ISISpace is utilizing the first true radiation hardened optimised for CubeSat applications. (MAUS)

Although the development was only initiated in 2019, the design heritage obtained with the development of the BiSon Sun sensors and the testbed development for the digital IBIS allowed for a quick turn-around development. In the meantime, the sensors have been fully qualified and several of them are flying on a number of ISISpace CubeSats. Among these the are the recently launched KSF1 & KSF2 KLEOS clusters as well as the NAPA-2 satellite.

The later not only flies some MAUS Sun sensors but also flies an Auriga star tracker, which is much more accurate than the Sun sensors, thus allowing accuracy verification.

The NAPA satellite has a LTAN of 14:30h, which is a poor orbit for Earth albedo influences on the Sun sensor accuracy. On the other hand, it is an excellent combination to show how Earth Albedo will affect the accuracy and verify this accuracy loss with the help of the high accuracy Start racker.

This paper will provide information on albedo errors generated on-orbit on basis of available and Star tracker data and consequently will show how our Blue and White Marble can ruin the accuracy of your Sun-attitude measurements.

1 ALBEDO SENSITIVITY

Attitude and altitude control are key for accurate satellite positioning, and one of the most common methods to control the satellite’s attitude and altitude is to measure its position with respect to the sun. Devices that perform these measurements are called Sunsensors, basically a position sensitive light detector. However, the majority of the satellites are operated near the Earth, consequently, the sun is not the only significant light source. Sunlight reflected from the Earth can be detected as well and can affect a precise position measurement. Sunlight reflected from Earth is called the Earth albedo, its corresponding input on a Sunsensor is called the albedo signal.

An albedo signal is not only generated by the Earth, other objects in the field of view such as antennas, solar panels etc. can generate an albedo signal as well. As albedo signals vary with the satellites attitude towards the sun and are highly variable, they cannot be compensated for and consequently lead to measurement errors. The Earth for instance is largely blue and white due the large water and ice masses and reflecting clouds. In addition, vast desert areas can also have a significant impact on the overall level of albedo signal. Therefore, the albedo signal strongly varies with spacecraft altitude and attitude, field of view and variables like cloud coverage.

Especially for low Earth orbiting satellites the albedo signal can generate large and foremost unpredictable errors in the spacecraft attitude. As a simple analogue sun sensor is not capable of discriminating between light which directly originating from the sun and light which is reflected by some foreign object, this leads to dominant measurement errors several times as high as the inherent accuracy that can be achieved with the same sensors in absence of albedo signal.

Figure 1 Earth seen from space
Source: https://sos.noaa.gov/datasets/blue-marble/

Where some of the albedo effects can be reduced by careful sensor placement and addition of straylight-baffles, the Earths albedo effect is impossible to eliminate for a conventional silicon based analogue Sunsensor. Hence the albedo signal generally generates serious attitude disturbances especially in low Earth orbit.

1.1 Analogue Sun sensor functioning

There are several ways in which an analogue Sunsensor can function, but in general they are classified as coarse Sun sensors or fine Sun sensors.

For Coarse Sun sensors, the cosine dependence of the generated current as a function of the angle of incidence or the cosine response including the effect of a knife edge is considered.

Fine Sun sensors are more accurate sensors where in general an aperture is used to generate a number of measurement signals for which the ratio of generated currents is used to calculate the angel of incidence. Using an aperture means that the maximum measurement angles are more restricted, and a hemispherical field of view is not possible without using additional optics. Using the ratio of generated currents means that fine Sun sensors are less sensitive to temperature variations, contamination or radiation degradation because common mode effects are automatically cancelled. In addition to this, the membranes are generally deposited on rather thick glass carriers which will provide additional radiation shielding over the commonly used cover glasses for coarse Sun sensors.

The functioning of the fine Sunsensor produced at Lens R&D is given in below figure1.

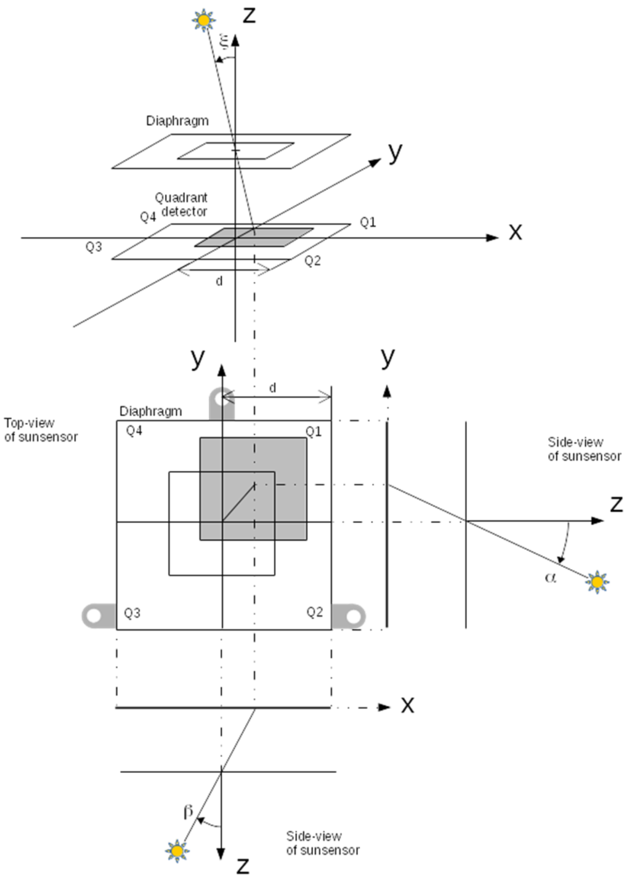

Figure 2 Analogue Sunsensor principle

The sunlight enters the sensor through a membrane and produces a sunspot on the 4-channel detector surface. By reading the four currents generated and applying a goniometric formula, the angle of incidence can be calculated. It should be obvious that any other source than the sun will also generate a spot on the detectors. As the detectors cannot discriminate against the origin of incoming light, the sum of the signals will be output, thus generating an error caused by the additional input source (the albedo signal).

Looking at Figure 3 below, it can be appreciated that depending on how much earth and satellite parts are in the field of view, a significant albedo signal can be generated.

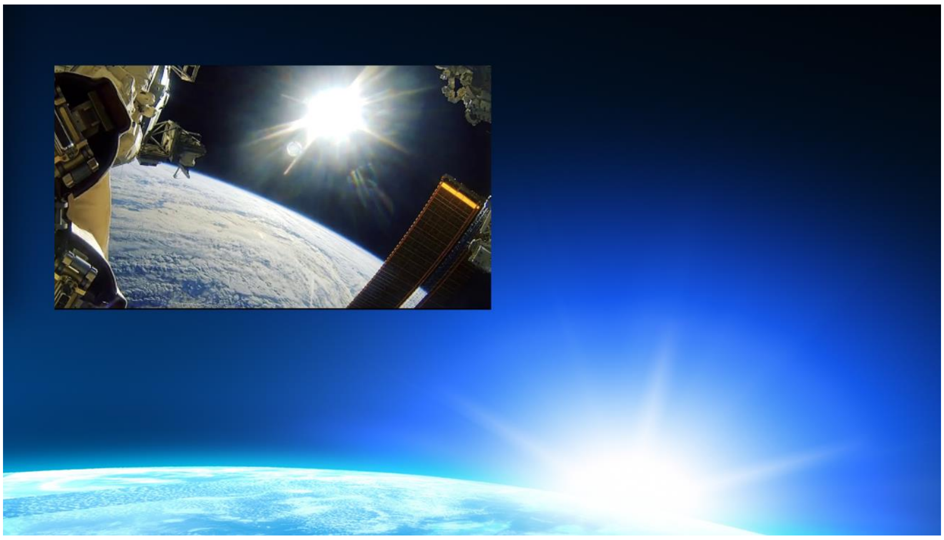

Figure 3 View from space

1.2 Sun sensor current profiles

When looking at the currents generated in Orbit (as shown in Figure 4) it is striking to see that the currents are not evolving nice and smoothly. The currents are larger than anticipated but also irregular. Both phenomena can be attributed to Albedo signals.

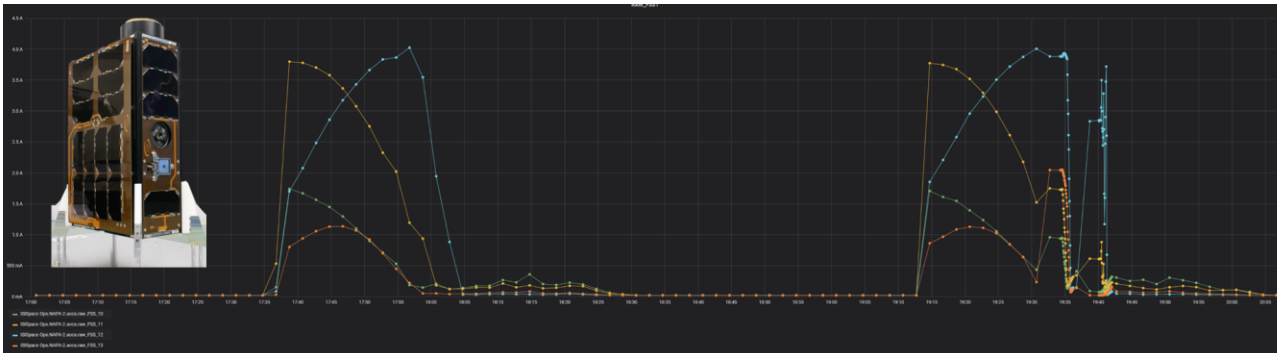

Figure 4 On orbit sensor currents

The generated currents are significantly higher than expected without Albedo signal and under circumstances can even lead to saturation of the input circuits (as can be seen on the righthand side of the graphs.

Looking at the graph it can also be seen that despite the absence of Sun illumination albedo generates a significant signal during large parts of the orbit. (As long as the satellite is not in eclipse)

The NAPA-2 satellite is orbiting the Earth at 550km with a local time ascending node of 14:30h. This local node time and comparatively low altitude aggravate the albedo error issues. This is the reason why NAPA-2 is an excellent test bed to show the effect of albedo errors on attitude measurements.

1.3 Comparison Star tracker attitude versus Sun sensor attitude.

As mentioned, the NAPA-2 satellite has three Sun sensors and 1 star tracker. One of the Sun sensors is Zenith pointing and will therefore not (or barely) see the Earth (and will consequently not be affected by Earth's albedo.

This can be clearly seen when looking at the differences between the three sensors and comparing the errors that are found while comparing with the attitude as determined on bases of the Star tracker data.

For the next graphs, the dotted lines represent the Star tracker attitude, the solid lines the attitude as determined on basis of the Sun sensor data.

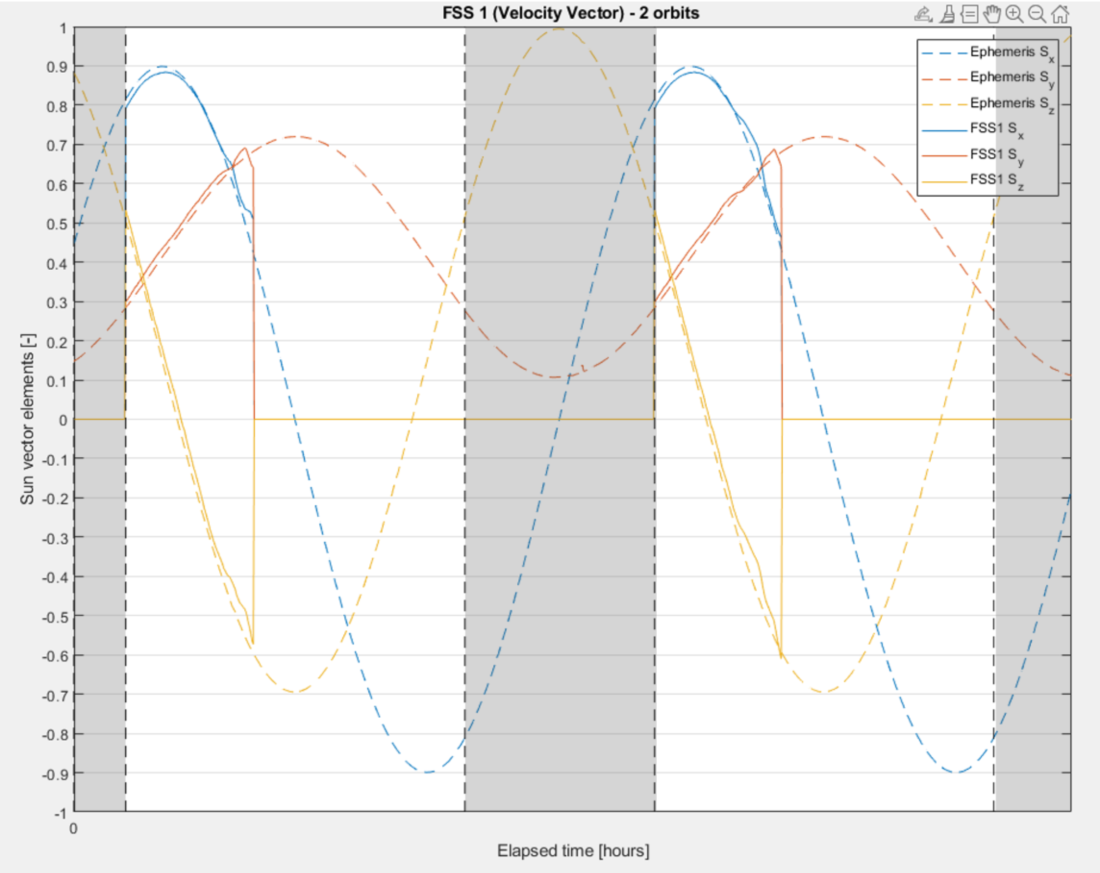

Figure 5 Attitude as measured by FSS1

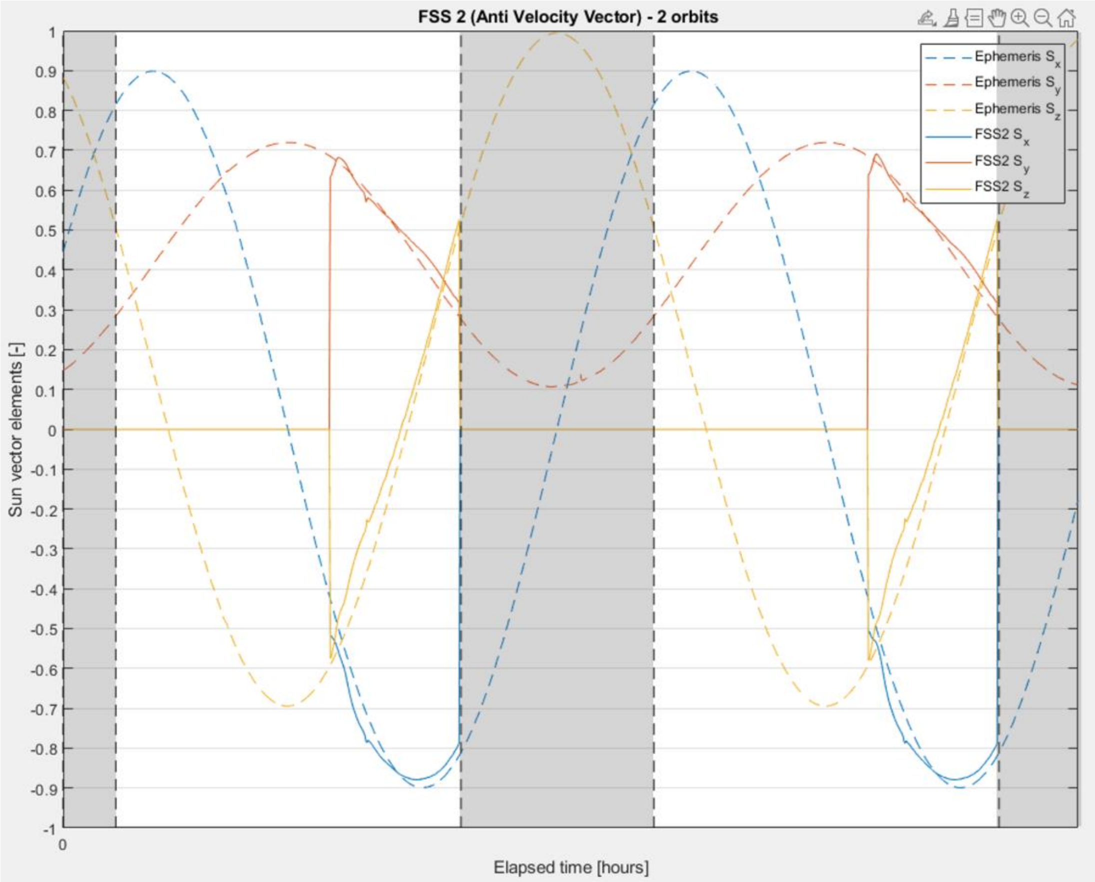

Figure 6 Attitude as measured by FSS2

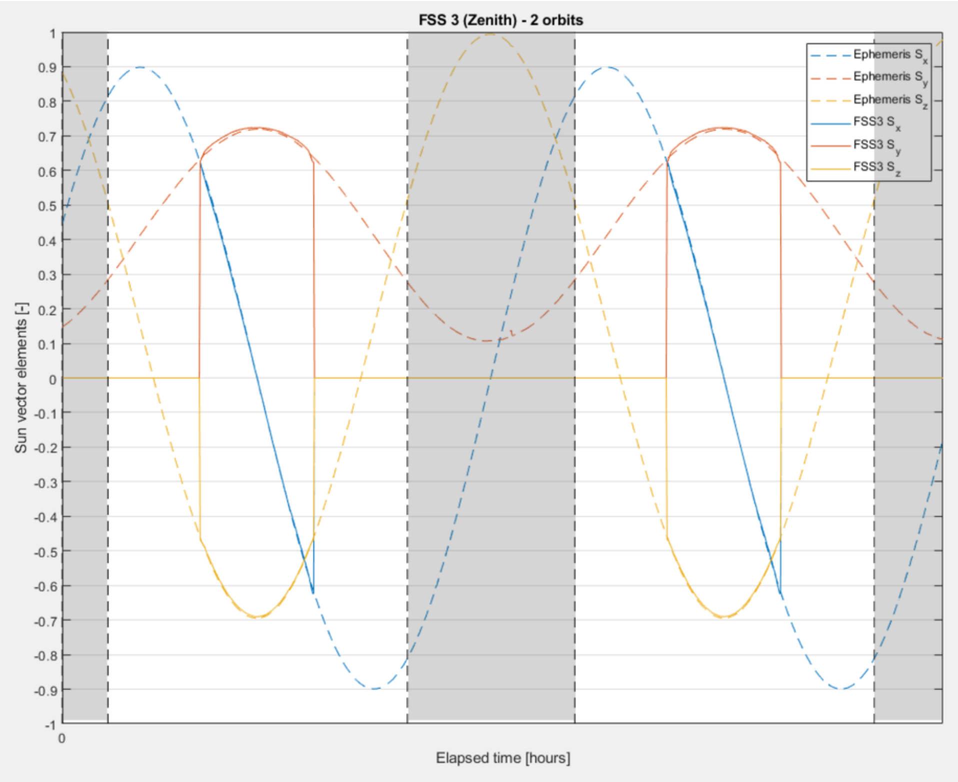

Figure 7 Attitude as measured by FSS3 (Earth albedo free)

From these figures it can be clearly seen that FSS1 and FSS2 show significant deviations, where FSS3 follows the Star tracker attitude much closer. The differences can be clearly seen while looking at the errors between the Star tracker and Sun sensor attitude data as shown in Figure 8,

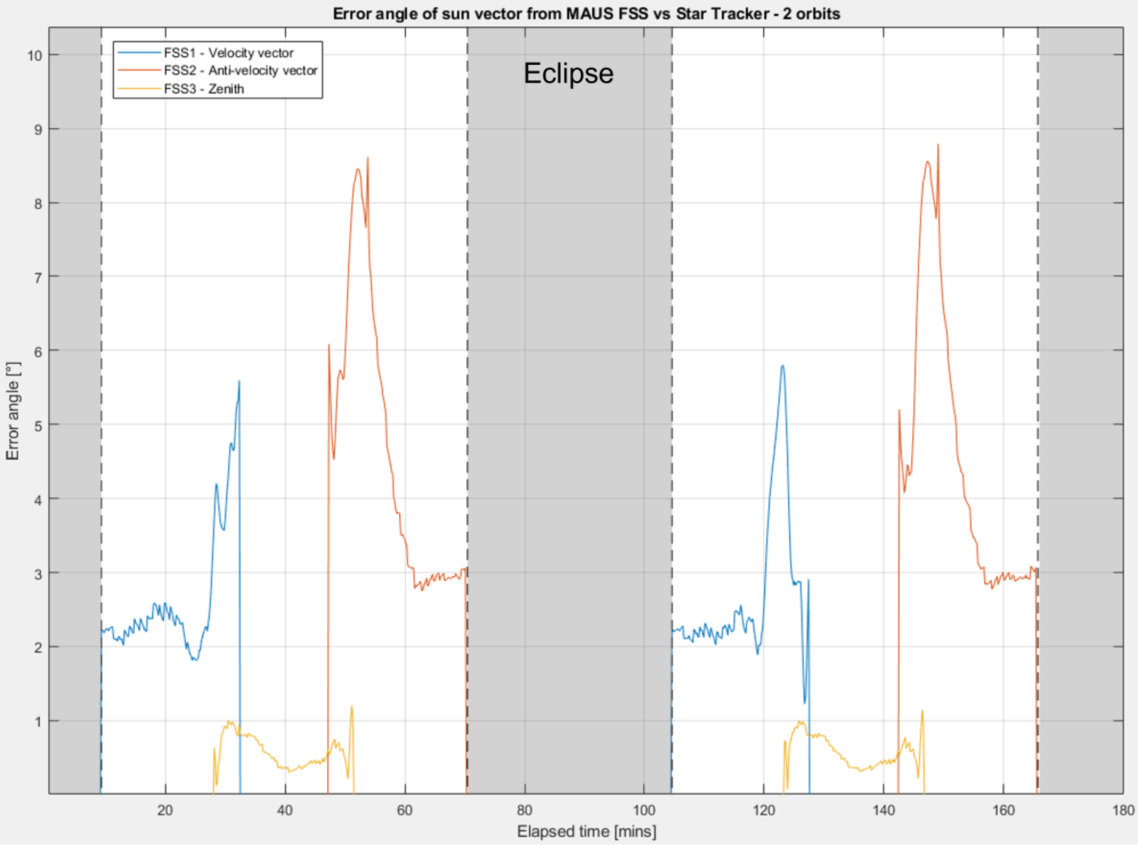

Figure 8 attitude errors

where the Zenith looking sensor provides a quite accurate attitude, the other two sensors not only shown a constant pedestal but also peak errors up to 5.5° and 8.5° respectively.

It should be noted that errors shown are the magnitude between the Star tracker vector and the Sun sensor vector but don't provide any direction information. Further analysis however has shown that the vector is shifted towards the XY plane, when the satellite is Earth pointing. This confirms that the error is caused by Earth's albedo.

The largest errors are seen when the sensor is looking at a Sun in such a way that specular reflections also contribute to the albedo signal. For angles where specular reflections are not reaching the satellite anymore, diffuse reflection still cause errors that are 2° and 3° respectively, causing the observed pedestal. While at an attitude that allows specular reflections, the albedo generated error is not only significantly higher, but it can also be observed that the variability of the signal is significant. Sea state and reflections on ice surfaces can cause large signal peaks, but only for a relatively short period of time.

The large albedo errors present while changing from one sensor to the other can lead to stability issues in the attitude control loop of the satellite when changing from one sensor to the other and therefore it is advised to include a preference for the sensor with the lowest albedo influence if given the opportunity.

2 CONCLUSIONS:

Evaluation of the Sunsensor generated currents show that albedo signal can lead to saturation if not properly taken into account.

Comparison of Star tracker attitude measurements and Sun sensor attitude measurements have shown that albedo generated signals quite often have a significant effect on the attitude accuracy when using Sun sensors for attitude determination.

Careful positioning of the sensors can therefore significantly increase the fidelity of the attitude measurement.

Area's where specular reflections are present lead to significantly larger albedo errors with a higher variability

When availability allows, the signals from an albedo free sensor should be given preference over the signals from a sensor that is hampered by albedo, as this will significantly increase the accuracy of the attitude determination.