Low-Power Custom-Built Sun Sensors For Nanosatellite

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Abstract

ESTCube-1 is a 1-unit CubeSat to be launched in mid-April, 2013. Its primary mission is to measure the Coulomb drag force exerted by a natural plasma stream on a charged tether and thus to perform the basic proof of concept measurement and technology demonstration of electric solar wind sail technology[1].

The attitude determination and control system (ADCS) performs detumbling, pointing and high rate spin control of the satellite[2]. The attitude determination system uses three-axis magnetometers, three-axis gyroscopic sensors and two-axis Sun sensors, one on each side of the satellite. While commercial off-the-shelf components are used for magnetometers and gyroscopic sensors, Sun sensors are custom-built based on analogue one-dimensional low-power Position Sensitive Detectors (PSD).

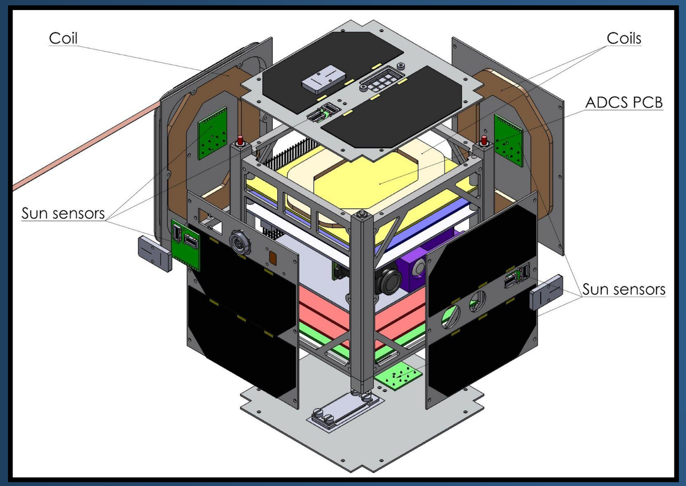
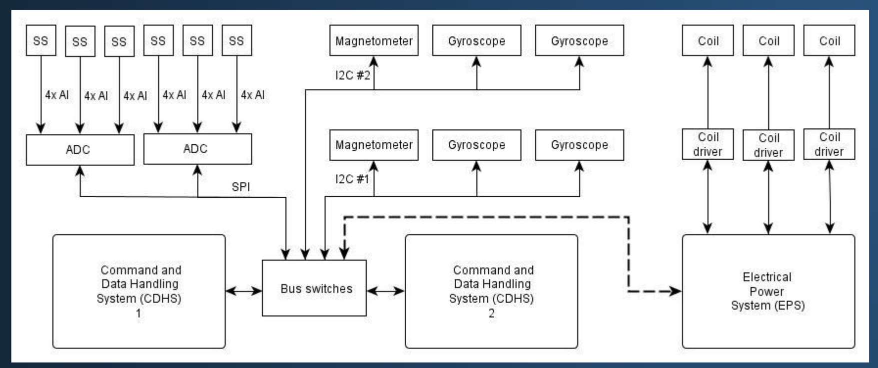


Figure 1: *ADCS hardware layout*



Sun Sensor Design

Figure 3 shows Sun sensor hardware layout. Two PSDs are located under a mask with two slits perpendicular to corresponding PSDs. Light beam travels through a slit and when reaches a PSD, introduces photocurrent. Depending on position and intensity, two outputs are generated which are converted to voltages and measured using analogue to digital converter (ADC). Given spot light positions on PSDs, height of the mask and illuminated side of the satellite, direction of the Sun can be calculated.

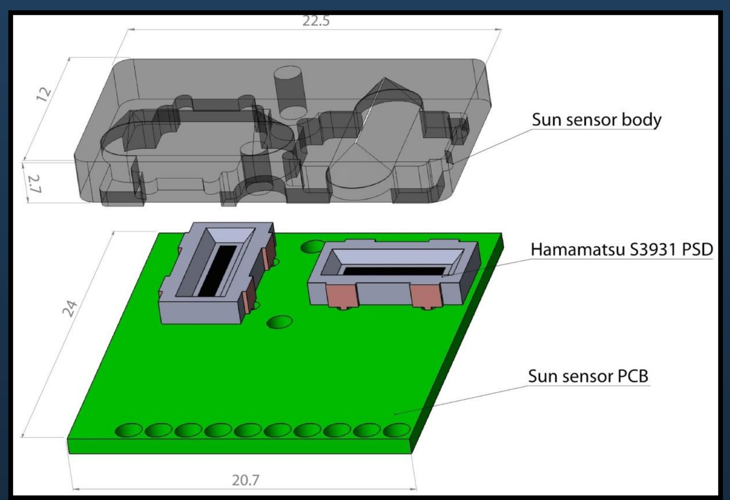


Figure 3

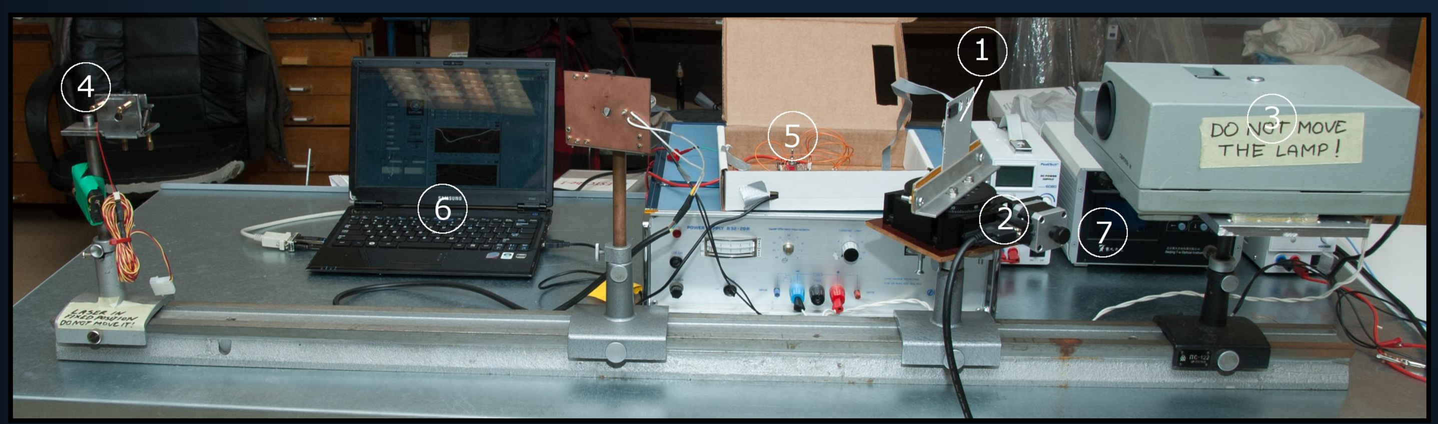


Figure 4: *Angle test setup: Sun sensor (1), rotating bench (2), light source (3), laser (4), electronics board (5), computer (6), rotating bench controller (7)*

Testing

Sun sensors are thoroughly tested for two reasons. First, to define accuracy and, second, to qualify for space environment. The main influential factors are temperature, vacuum, radiation, response characteristics, noise and geometrical, optical and electrical properties that are not ideal.

Angle test provides calibration data and indicates field of view. Figure 4 shows the test setup.

Temperature test indicates if sensors work in expected temperature range (from -30°C to 40°C) and provides measurement dependency on temperature. Figure 5 shows the test setup. A sun sensor (1) is in a thermal chamber (2). It is illuminated through a hole by a light source (3) which located outside the chamber. Three temperature sensors (4) are used. All readings are gathered by a LabJack U9 ADC (5) and processed by a computer (6).

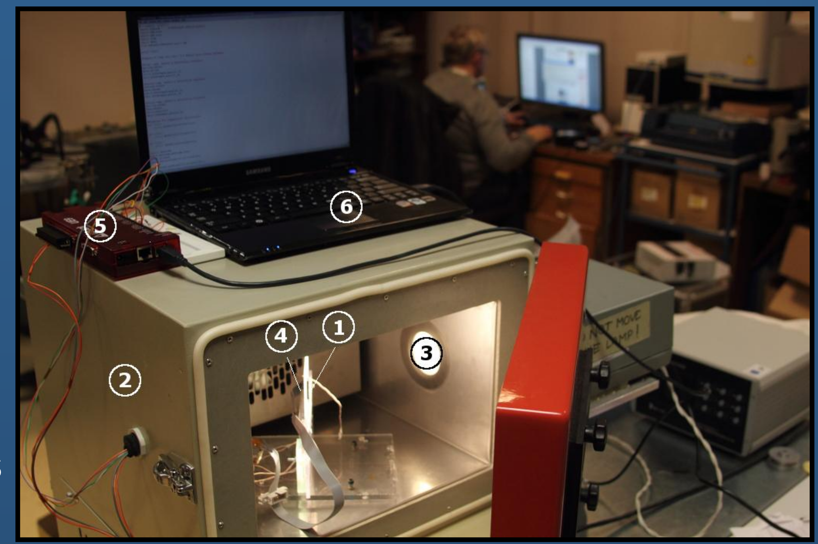


Figure 5

Irradiance test indicates how sensor responds to increasing irradiance. The test shows if sensors get saturated by irradiance level expected in space which is 1353 W/m^2.[3]

Vacuum test indicates if vacuum causes permanent damage to sensors.

UV test indicates if ultraviolet radiation causes permanent damage to sensors.

Results

Angle test. Figure 6 shows measured incident light position dependency on rotation angle.

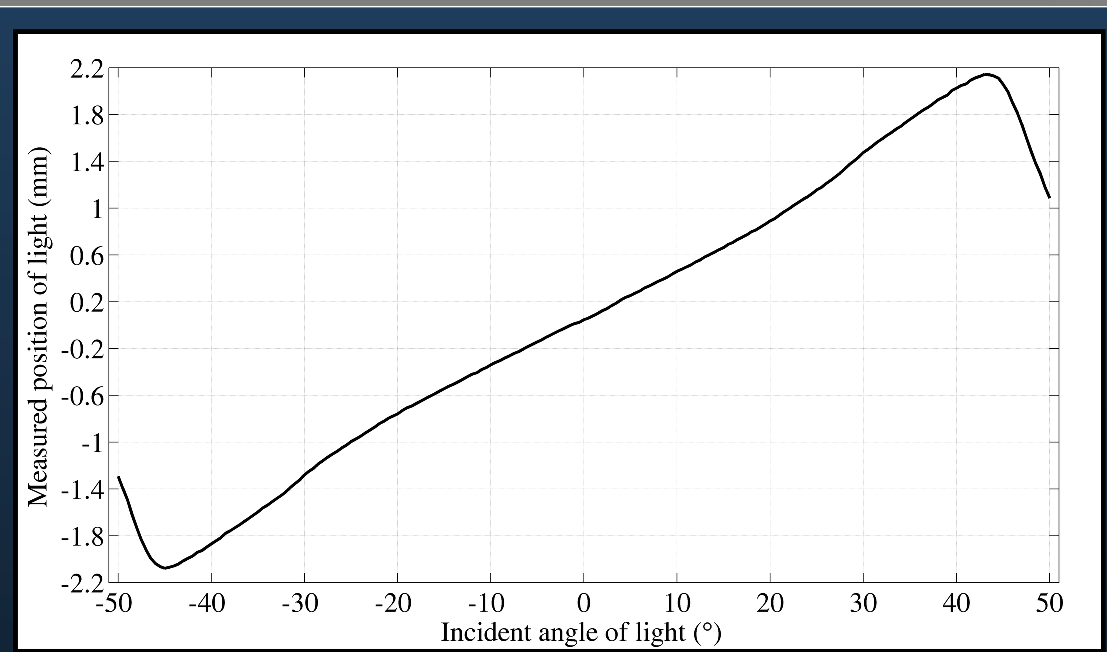


Figure 6

Temperature test. Figure 7 presents three temperature tests, where Sun sensor was illuminated at three different angles. These results show that the indication of apparent position shifts when temperature is raised.

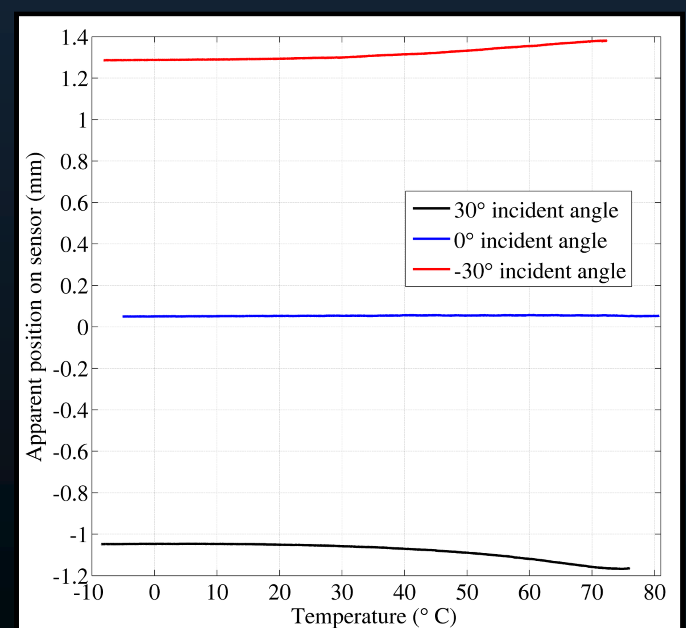


Figure 7

Irradiance test. Figure 8 shows the standard deviation of angle test results with different light irradiance values, where irradiance was increased from 1000 W/m^2 to 1800 W/m^2 and kept constant through a single test. The deviation is calculated for all measured angular positions.

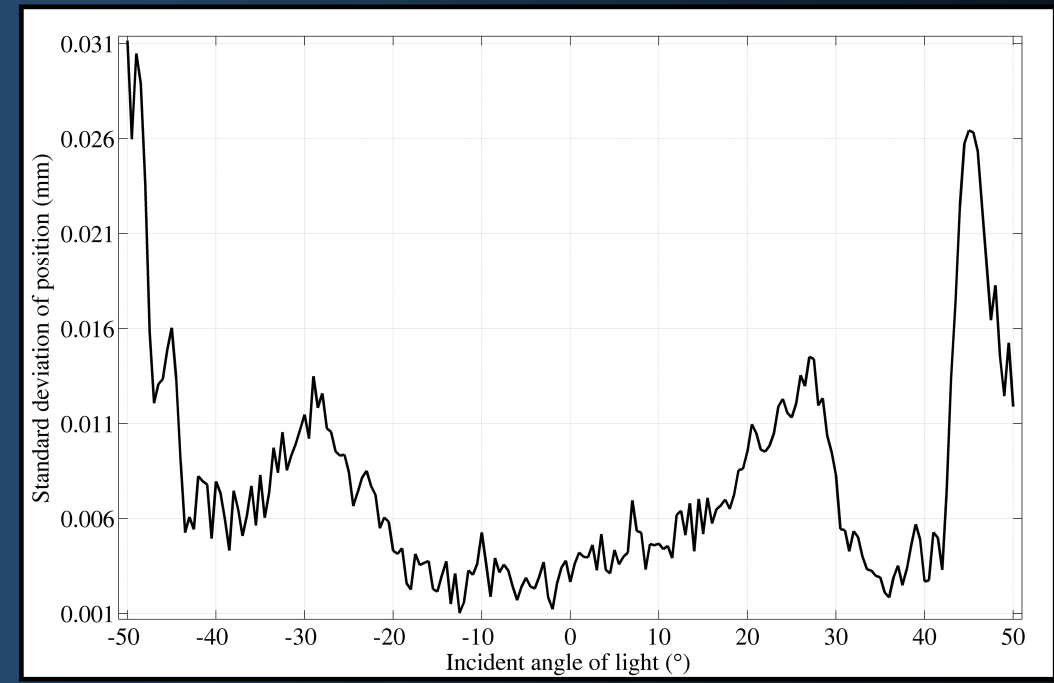


Figure 8

Vacuum test. The pressure value during vacuum test was 26 Pa and results indicate that there is no permanent damage if before and after test results are compared.

Uncertainty budget

δP_T - Temperature drift
δP_I - Irradiance drift
δP_P - Precision of position angle measurement
δ_R - Rotation bench resolution error
δP_S - Statistical error of single angular measurement during calibration
δP_{ADC} - ADC temperature parameters

Quantity	Estimate	Standard uncertainty	Probability distribution	Uncertainty contribution
δP_T	0 °C	26 °C	rectangular	0.755 deg
δP_I	1353 W/m^2	231 W/m^2	rectangular	0.157 deg
δP_P	0 mm	3.75×10^{-3} mm	normal	0.081 deg
δR	0.005 deg	1.44×10^{-3} deg	rectangular	0.0015 deg
δP_S	0 mm	1.7×10^{-4} mm	normal	0.004 deg
δP_{ADC}	0 V*mm	2.5×10^{-3} V*mm	rectangular	5×10^{-5} deg
Sum 95% confidence level, coverage factor k=2				1.55 deg

Conclusions

Custom-built Sun sensors were tested in conditions expected in low Earth orbit. These pre-launch test results indicate that Sun sensors can operate in space environment. Uncertainty is estimated to be 1.55 deg. It could be reduced by creating an analytical model of the sensor which takes the most influential physical quantities into account, e.g. temperature, to interpret measurements. The choice to develop a sensor instead of using commercially available devices has justified itself because the development process has provided great technical knowledge and valuable educational experience. Performance of Sun sensors fulfill the requirements of ESTCube-1 mission.

References

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[2] A. Slavinskis, U. Kvell, E. Kulu, T. Scheffler, S. Lätt, M. Noorma, Magnetic attitude control algorithms for ESTCube-1, *63rd International Astronautical Congress*, 2012.
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