Cost Efficient Space Micro-Switches Based on Contactless Eddy Current Sensors

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Abstract

Micro-switches are frequently used in space mechanisms to provide telemetry or to provide positive indication of the achievement of a desired position or function such as open, close, ready-to-latch, latched, end of travel, reference position, and for different mechanism applications.

Current switches that rely on electro-mechanical technology are not very reliable and are sensitive to mounting orientation, to thermal gradients, and have a limited number of operational cycles, which is a problem for long life application, launch vibrations and shock loads.

Micro-switches relying on contact, as well as relay reeds, provide additional resistive torque that has to be overcome by the mechanism actuator, having a negative impact on the motorization margins.

In this paper, CEDRAT TECHNOLOGIES presents the design and tests results of contactless micro-switch devices, based on Eddy Current Sensors (ECS) technology, and with embedded conditioning space-grade electronics. This development was achieved under an ESA R&D space program, in order to develop micro-switch devices not affecting reliability of mechanisms, not adding extra mass nor any resistive torque, and with the major objective of achieving very high cost efficiency for space applications with large quantities, such as for New Space constellations.

The design has been achieved for two sensing configurations, one for axial motion, and the second for tangential motion. The test results of a batch of Engineering Qualification Models are presented for sensing precision, space environmental temperature conditions, launch vibrations and shock tests, spacecraft Electro-Magnetic Compatibility (EMC) tests, and radiation environmental tests up to 300 Krad.

Introduction

For many years, CEDRAT TECHNOLOGIES (CTEC) has been developing and qualifying miniature sensor technologies in the field of space fine pointing and positioning applications, based either on strain gauges for piezoelectric mechanisms, or Eddy Current Sensors (ECS) for magnetic ones.

ECS sensor technology is currently a major topic of interest, especially in the field of scan mirror mechanisms, fast steering mirrors (FSM), fine pointing mirrors, and in the field of reference sensor for proximity detection such as micro-switching and tachometer sensors, for either ambient or cryogenic space temperatures.

For the last few years, the field of new space applications such as giant constellations requiring very large quantities, with both high reliability and high cost efficiency, has led to the increase of ECS technologies development for proximity detection in deployment mechanisms. The maturation of CTEC ECS technology in that field was first started under CNES funding, and is then being continued under ESA funding for micro-switching applications.

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Figure 1. ECS-Based Micro-Switch Sensor

Micro-Switch Sensor Design Description

<u>Design and Integration Concept Overview</u>
Two micro-switches have been designed in order to provide either axial detection or tangential detection, both having the same housing and interface design, and each having a dedicated sensor head configuration.

The sensing head is located at the tip of a cylindrical body which provides an M16 fastening interface over the complete body length, and which also provides the housing for the embedded conditioning electronics. This design has been proposed in order to provide cost efficiency, as well as simple integration onto structures with precise sensing clearances adjustment, and easy electrical connection to a distant power source without requiring any remote signal conditioning.

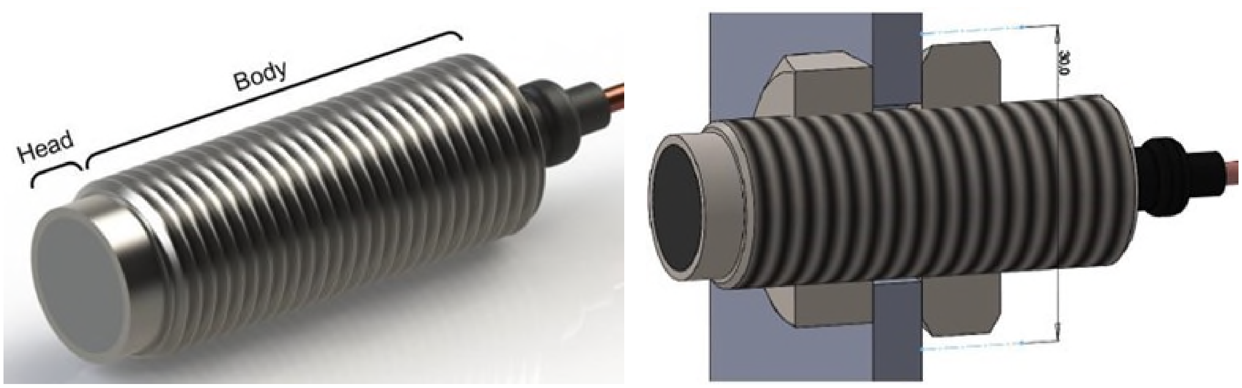

Figure 2. Micro-Switch Design and Integration Concept

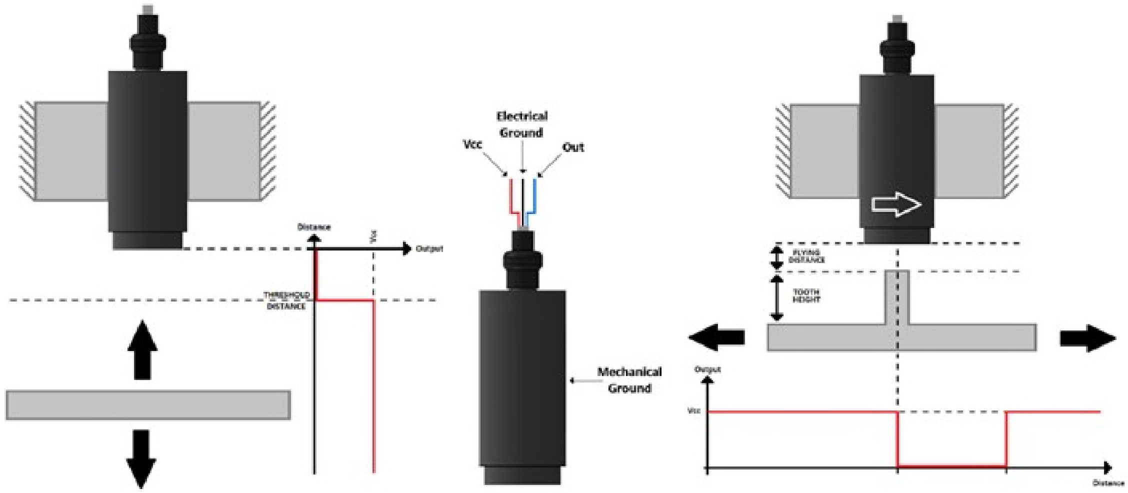

Figure 3. Axial motion micro-switch design (left) and tangential motion micro-switch design (right)

The sensor operates with a push-pull voltage output, which provides a digital output indicating the proximity of a target located onto a moving part. A high level (VOUT = VCC) means that the target is far from the sensor and a low level (VOUT = GND) means that the target close to the sensor.

The approach of a high output level when the target is far from the sensor was defined for safety concerns, in case of sensor failure. If a failure does occur, the output is set to low level, as if indicating the proximity of the target is in front of the sensor, in such a way that the mechanism motion can be stopped to avoid a collision, in order to activate a redundant sensor.

Figure 4 illustrates the clearances to be adjusted at integration (red colors), at end of stroke of mechanism i.e., at mechanism motion stopping, thanks to the M16 fastening / positioning interface.

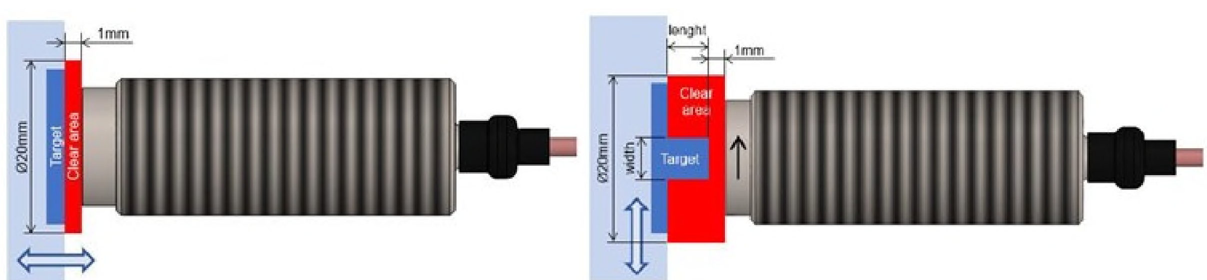

Figure 4. Micro-Switch proximity clearance for axial motion (left) and tangential motion (right)

The cylindrical body of the sensor which serves as the fastening interface also provides the housing for the conditioning electronics, which will detect and quantify the inductance and resistance variations difference between two measurement coils, based on differential measurement principle. The void volume of the housing all around the electronics Printed Circuit Board (PCB) is filled with potting, in order to avoid any air entrapment, and to provide thermal heat sinking toward mechanical interfaces.

The major advantage of the differential measurement approach between two coils is the insensitivity to thermal variation of the environment, as the thermal drift is applied to the two coils with the same effect, and cancelled by differential subtraction. Figure 5 illustrates the architecture of the embedded conditioning electronics.

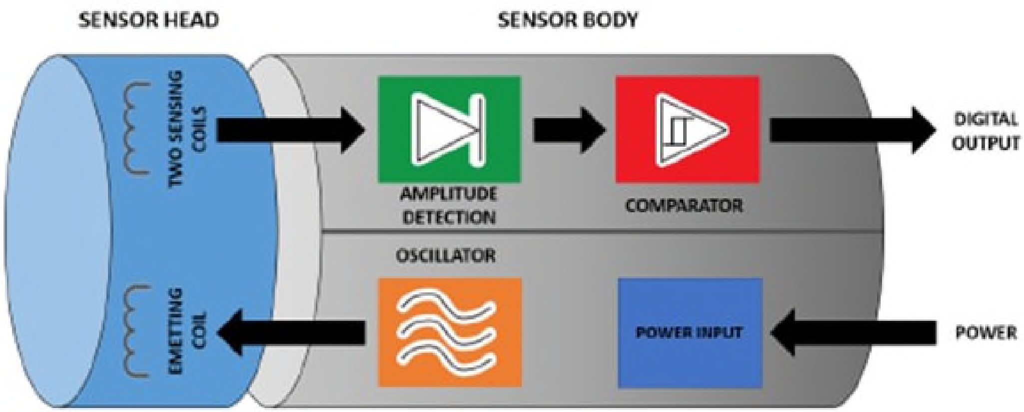

Figure 5. Micro-switch embedded conditioning electronics

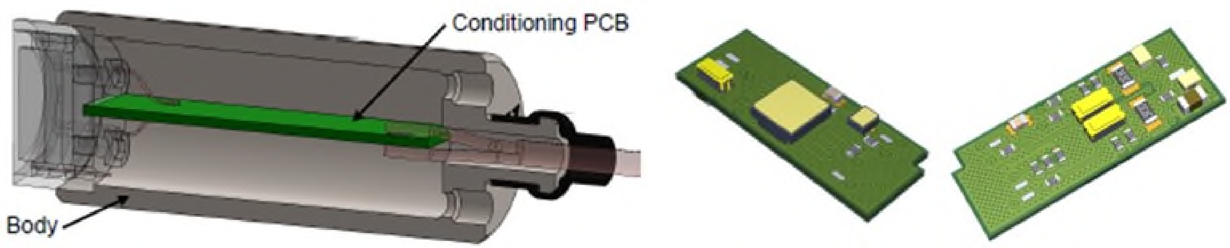

Figure 6. Micro-switch embedded space-grade conditioning PCB design

The sensor head, body, and conditioning electronics are independent prior to final assembly, and can be modified separately. This feature enables multiple sensor configurations without impacting outer design or dimensions, in order to provide either tangential or axial motion detection of a distant target located on a moving part.

With same mechanical design configuration, other sensing heads and conditioning electronics can be customized to fit with customer requirements, in order to provide specific threshold distances, and specific operational conditions from high to cryogenic temperatures.

<u>Axial and Tangential Sensing Heads Configurations</u>

The sensing principle of the micro-switches proposed are based on the eddy current measurement principle, requiring emitting and sensing coils implemented onto a space PCB. The emitting coil generates eddy currents on a distant target surface, with a small electrical excitation at high frequency, typically adjustable between 500 kHz to 5 MHz. This signal is based on Colpitts oscillator, the emitting coil being part of the current tank in such a way that the emitting function requires a very low power to provide the required high frequency magnetic field oscillation.

According to Lenz's Law, the direction of the eddy currents induced on the target conductor by the oscillating magnetic field generates an opposite magnetic field opposing to the emitted one in such a way that variations are observed in the sensing coil inductance values as function of the distance to the target.

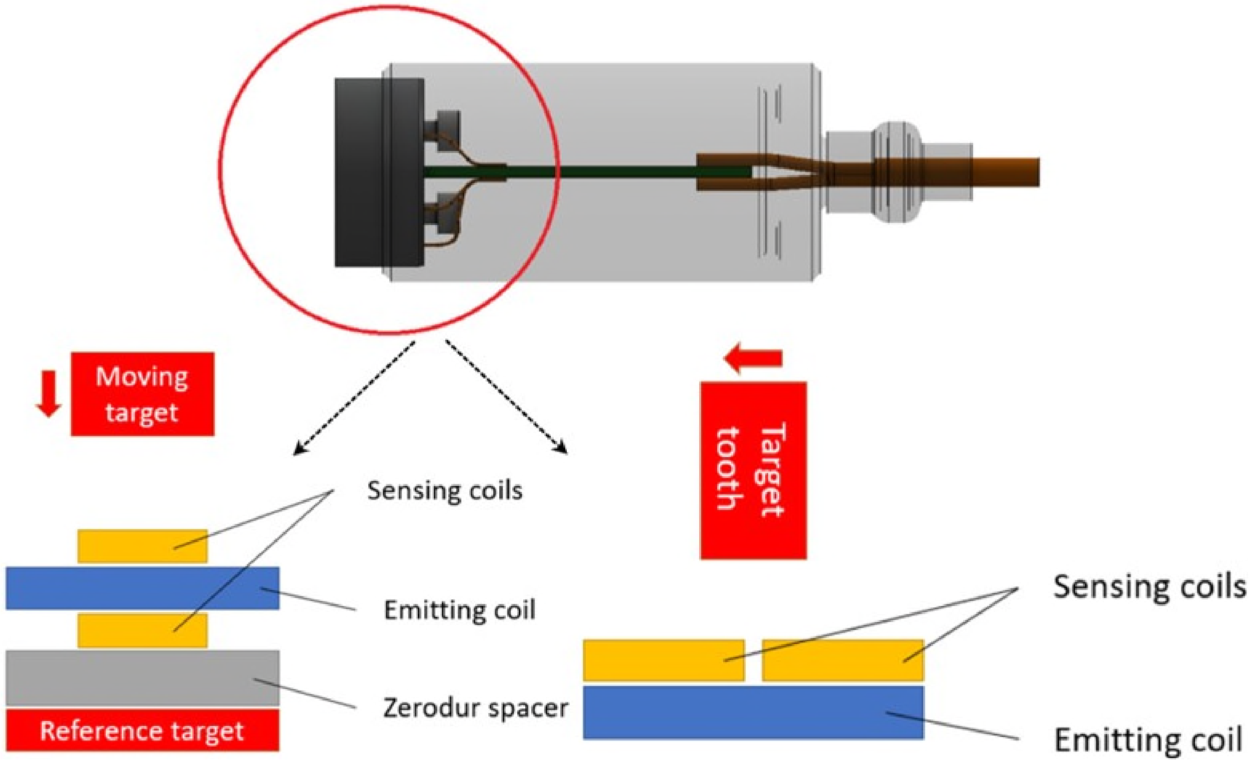

Figure 7. Emitting Sensing & Sensing coils configurations, axial (left) and tangential (right)

Manufacturing of Engineering Qualification Models (EQM)

The project which is still ongoing has allowed the manufacturing of a batch of four Engineering Qualification Models, two in axial motion detection, and two in tangential. Figure 8 shows the space design achieved, with the space design of embedded conditioning electronics.

Figure 8. Batch of Four Engineering Qualification Models

The embedded conditioning electronics were designed and manufactured according to space-grade standards, considering the PCB applicable design rules as well as materials. All active components included in the PCB are space Engineering Models.

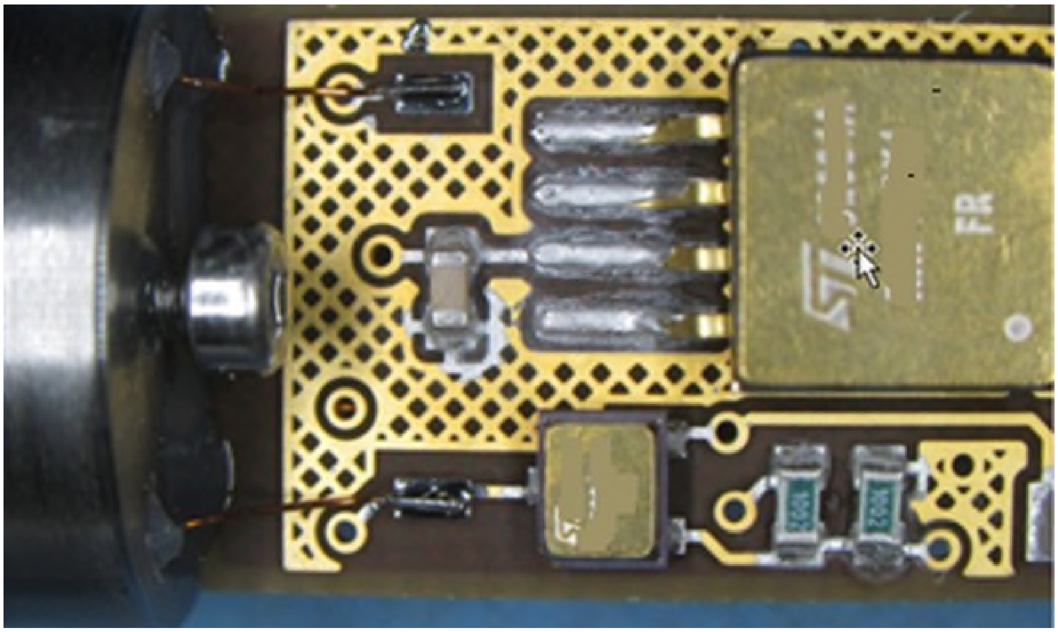

Figure 9. Space Grade EQM Embedded Conditioning Electronics

The performance test bench was realized based on a commercial reference position sensor and the use of a voice coil actuator implemented onto flexure bearings, in order to simulate a proximity motion of a moving part without friction.

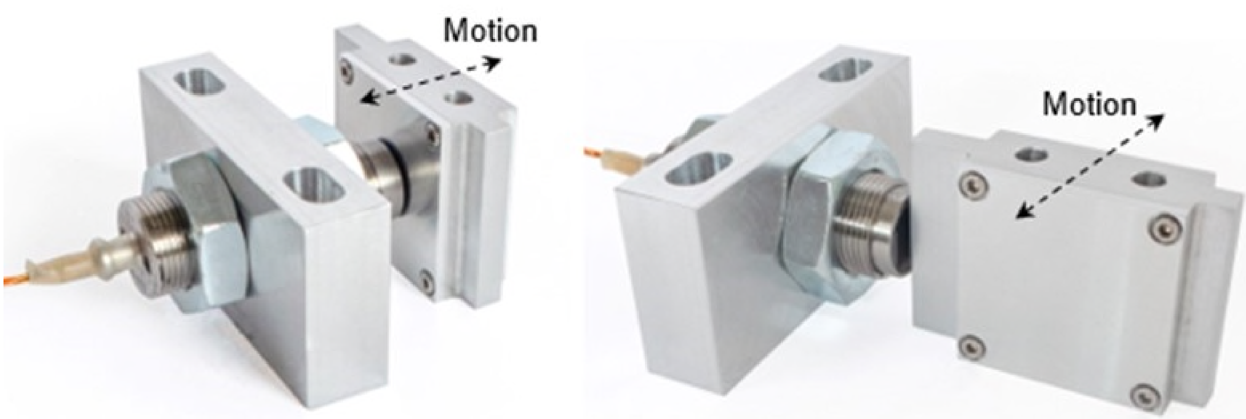

Figure 10. Sensing motion test bench principles, axial (left) and tangential (right)

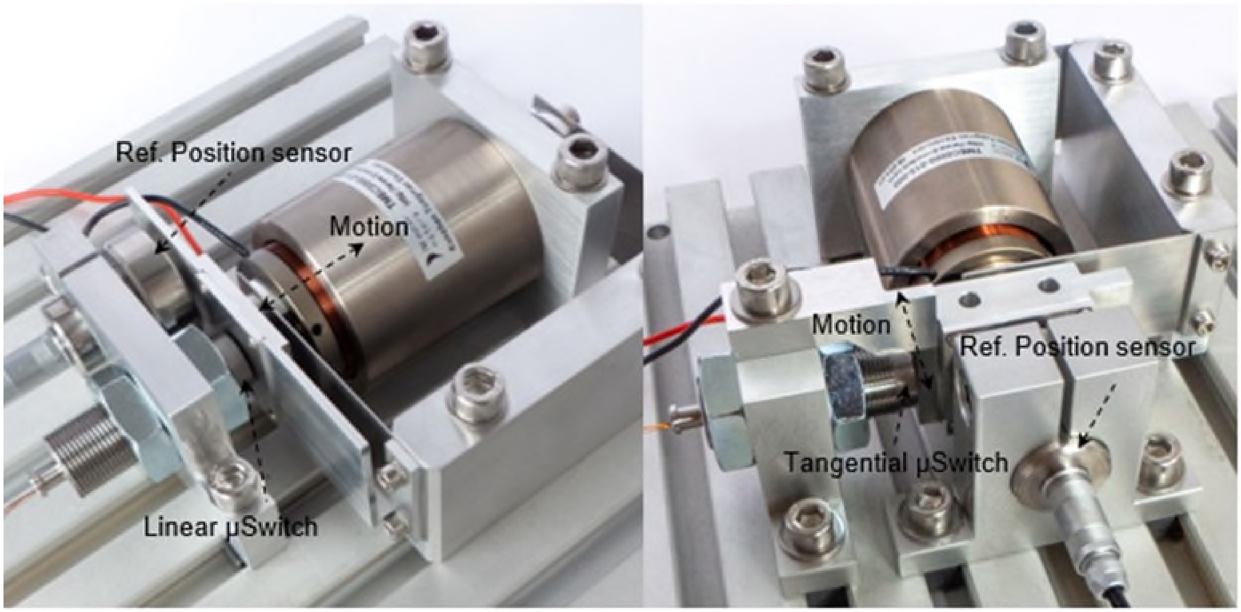

Figure 11. Sensing performance test bench, axial (left) and tangential (right)

At the time of the current publication, the proximity detection principle has been successfully tested, with accuracy demonstrated lower than 50 µm. The hysteresis error during cyclic forward and backward motions has also been evaluated to about 20 µm, but this does not need to be taken into account when using the micro-switch to detect end of stroke in such applications as deployment mechanisms.

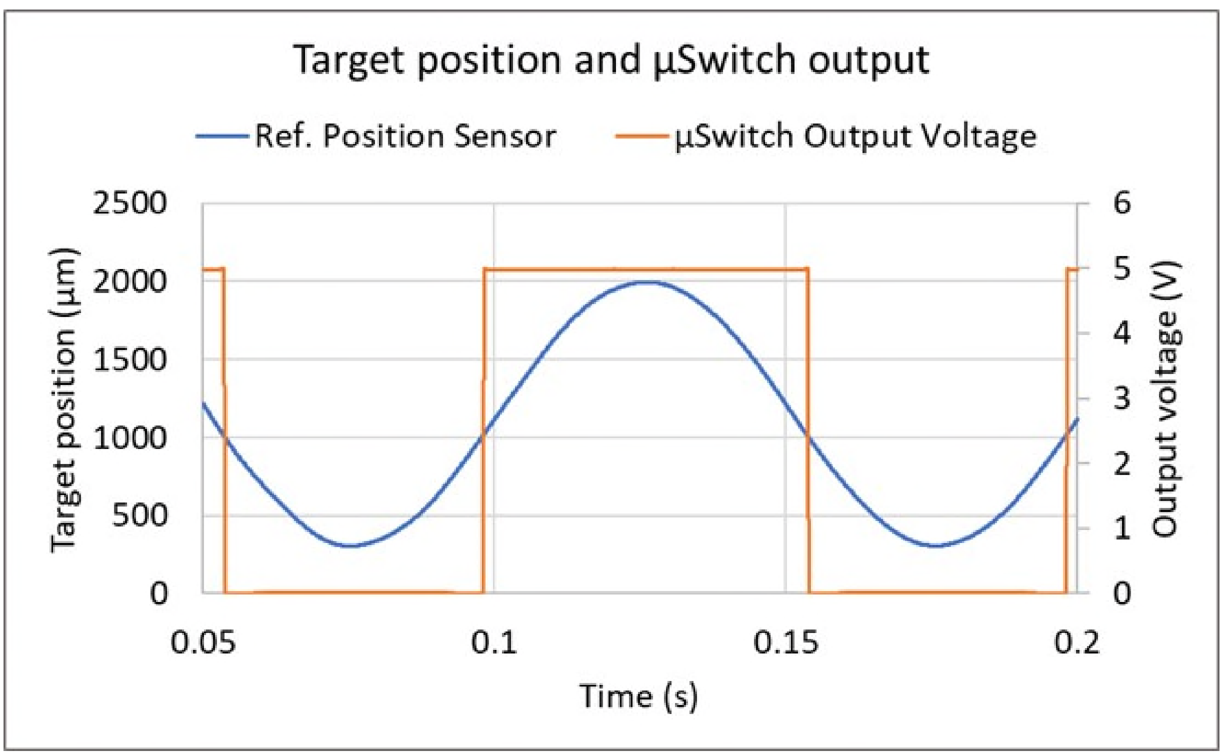

Figure 12. Sensing Test Results – Proximity Detection

Figure 13. Sensing test results – Forward / backward hysteresis threshold

The qualification test campaign shall be completed by the end of 2022 to fully demonstrate all environmental requirements by test.

Table 1 summarizes the performances expected of the proposed micro-switch design, as well as expected recurrent cost which is a key driver of this technology in new space applications.

Table 1. Micro-Switch functional performances & recurring costs summary

Contactless Threshold distance	1 mm
Switching Function	Push-pull
Switching level - High	Power supply
Switching level - low	GND
Power supply	3.3 or 5V DC
Power consumption	<100 mW
Electrical interface	Pigtail with leads
Repeatability	≤10 µm
Accuracy	≤50 µm (1)
Response time	<1 ms
Mechanical interface / Overall dimensions	Ø16 x 50 mm
Mass	37 g
Operating temperature	-50°C to +90°C
Non-operating temperature	-60°C to +100°C
Radiative environment	100 - 300 Krad
Detection cycles	> 500 000
On / Off cycles	> 1000
Lifetime	< 22 years
Outgassing	TML <1%, CVCM<0.1%
1st mechanical resonance	> 200 Hz
Mechanical random vibration	0.5 g^2/Hz 60 Hz to 400 Hz
Mechanical shock	1500 g's 1000 Hz to 10000 Hz
Reliability	> 0.9999 with a confidence level of 95%
Recurring cost per unit	< 6k euros for 10 units < 4k euros for 100 units

(1) Depending on calibration reference sensor accuracy. Repeatability ≤ 10 µm is to be considered as most relevant performance.

Conclusion and Acknowledgments

The proposed micro-switch design has shown successful preliminary performance, not yet fully qualified, but which should ensure a space commercial exploitation at the end of the project. Qualification runs will cover functional tests at ambient and operational temperatures, vibrations and shock environments, EMC and radiation tests.

The maturation of CTEC space ECS technology was possible thanks to CNES and ESA support funding, which have allowed the development of relevant and compact sensing solutions in the field of fine pointing and fine positioning applications, which are currently being launched as off the shelf space products. The reader is invited to evaluate the application of CTEC ECS sensors technologies in the proposed references, especially in the field of new space applications, large size constellations, and pointing mirror mechanisms.

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