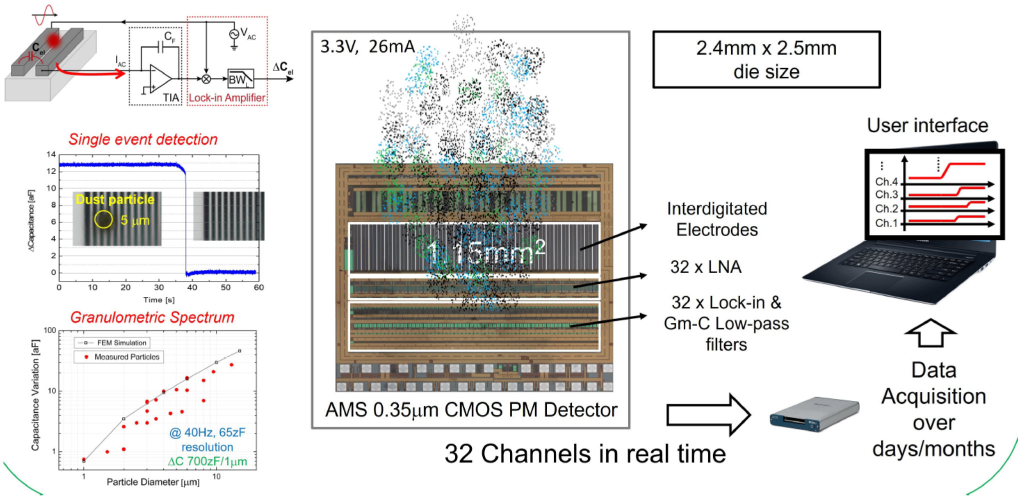


Real-time in-situ monitoring of particle deposition with on-chip electronic dust counter (DUST : DUst System Tracker)

Executive summary

Early technology development

IDEA I-2023-01289

Affiliation(s): Politecnico di Milano

Activity summary:

The project resulted in a miniaturized (3x2.4x0.5 cm^3) electronic sensor system for real-time monitoring of dust deposition on the sensor surface. It is based on an integrated electronic CMOS chip that tracks the capacitance variation between two interdigitated electrodes affected by the arrival of dust, ensuring single-event monitoring of particles with a diameter in a range from 20um down to 1um. The system features a low-power STm32 microcontroller for setting the chip operation, an analog-to-digital converter for the acquisition of the particle deposition events, a USB/Bluetooth transmitter for data read-out and all hardware and software functionalities that ensure proper user interface and completely autonomous operations over days-long acquisition.

Publishing Date: 9 December 2024
Contract Number: 4000141425/23/NL/GLC/ov
Implemented as ESA Initial Support for Innovation

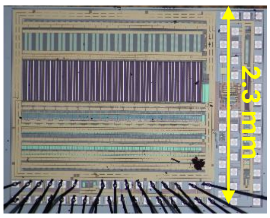
1. Introduction

The project aimed at developing a miniaturized fully electronic system for real-time monitoring of the amount of dust particles depositing on it. The project of this Electronic Dust Counter has been targeting avionics and space mission's requirements, where particle contamination can alter the operation of instruments and scientific payloads, by providing a measure and a verification of the deposition events on space hardware during fabrication, assembly and in the launch phase as well as during long missions. Therefore, the system has been designed to be miniaturized, robust to shakes, precise in the counts, simple in operation, consuming minimum power and allowing long-term dust tracking over weeks or months. The objective of the project was to demonstrate that such an innovative system is suitable for being considered by the space industry and fulfills its requirements in tracking dust levels over use in long missions and in providing a log file of the "particle contamination" lifeline on the sensor site.
The following of this document details the realization of the system and its performance in the detection and tracking of particle matter (PM) depositing over its surface.

2. Project Background

Airborne Particulate Matter is the subject of scientific and engineering attention for the vast implications of its monitoring in industrial, health, and scientific fields. Standard instrumentation, based on gravimetric or laser scattering detection methods, is typically bulky and complex, housing mechanical and/or optical subsystems therefore inappropriate to be distributed inside any space apparatus while being fabricated or in a final product that requires in-situ and real-time monitoring in a mission. The sensors based on MEMS technology, having suspended structures, are still considered too fragile for the envisaged Space Sector. More robust yet miniaturized sensors are currently available, like PFO plates or silicon wafers, allowing punctual estimation of the integral deposited particle contamination levels on sensitive surfaces, but they require ex-situ optical examination and therefore loose time information and cannot be integrated into a more complex apparatus nor can be used in space missions.

This project aimed at covering this gap by producing a miniaturized and robust system to measure in-situ and in real-time the contamination particle deposition on a surface, with log capability and digital transmission of the counts. The Electronic Dust Counter leverages an integrated CMOS chip (AMS 0.35µm) that the group designed and successfully tested in previous years, that counts in real-time dust particles down to 1 micron diameter. The chip operates by tracking with time the capacitance between two electrodes that will be affected by the arrival of a dust particle between them. The chip has proved to reach a resolution of 65 zeptoFarad of detectable variation within a millisecond time-scale, ensuring single particle monitoring and a dynamic range of hundred thousand dust particles over a sensitive area of 1.15 mm^2.



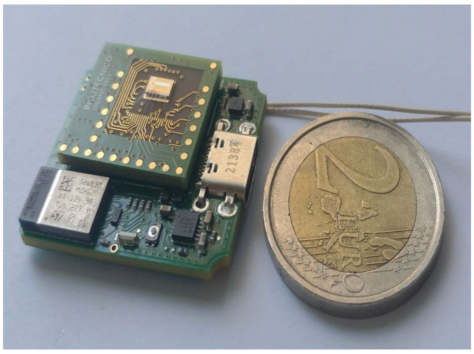
3. Methodology

We have integrated the sensor CMOS chip into a newly conceived electronic system that operates and monitors the chip, acquires electronic signals, and allows data transmission to a distant operator. We have finalized the prototype of the Electronic Dust Counter as made up of two parts:

i) a *main board*, compact in size (27mm x 30.5mm) and powered by a mini-USB cable, that contains an ADC for the conversion of the sensor chip output into digital data, a STm microcontroller for the sensor chip operation, a USB/Bluetooth transmitter/receiver for data read-out and monitoring and a mini-SD memory card connector for local mass storage and data lodging. The

STm32WB55RG microcontroller had been chosen as it holds in one package the crystal for the clock, a certified antenna for the bluetooth communication and an integrated USB protocol;

ii) a *smaller board* (18mm x 20mm) that houses the sensor chip and the components that locally provide the DC voltages for chip operation.



The two boards are connected through a 20pins miniaturized connector for data in/out analog/digital signals.

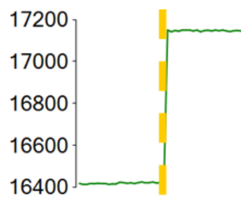
The STM32 microcontroller addresses in a cyclic turn-around all 32 sensor sections of the DUST chip, acquires its outputs for operational control and reads the differential impedance signals from the 16 bits ADC. The microcontroller fine-tunes the internal working points of the sensor chip and transmits the acquired data to an external PC either through USB cable or Bluetooth.
A computer coordinates the overall functioning of the system, sets the parameters used by the microcontroller and visualizes all desired and relevant data on a user-friendly interface. The power consumption of the platform is about 260mW and operates with a 5V input supply voltage (USB or autonomous).

The realization of the system in two boards has been motivated by the possibility of placing the smaller board at the site to be monitored, distant with respect to the main processing board, using a flexible cable-connector. Furthermore, the smaller board could be thought of being directly connected to the spacecraft electronic control system instead of to our main board, thus bypassing our main board, to facilitate and optimize system integration.

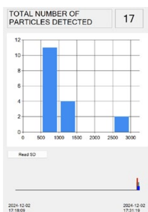
The system has been tested in its operation by dropping on its surface polymer microspheres of 8 micrometer in diameter (red fluorescent powder from Thermo Scientific). Their size comply with the interdigitated electrodes topology (1um metal electrodes – 1um spacing) and would be in the lower range of sizes expected in the space applications. A minimal amount of powder was blown toward the surface of the chip with the help of compressed nitrogen, to minimally modify the humidity level on the sensor. The electronic measurements of the dust deposition were routinely confirmed by a microscope inspection of the sensitive area of the chip sensor before and after the deposition test to visually certify the deposition of particles over the surface of each sensor.

4. Key Findings

The system has demonstrated to detect particle matter with very high resolution. The fluctuations in the differential acquisition when no particles were depositing, reflecting the **noise level of the system**, have been experimentally quantified in about **10bins** FWHM of the ADC over a full-scale range of 65000bins on all the 32 sub-channels of the detector. Conversely, in the operational tests of the platform, the signal produced by a 8um in diameter polymer microsphere resulted to be of more than 700 bins in the channels where a bead deposited (little depending on the position of the bead, whether over the electrode or between the electrodes). This gives a **Signal to Noise ratio of about S/N=70** for this size of dust particles, that ensures a clean detection also of much smaller particles and detection in harsh ambient with disturbances.



A user interface has been developed to input the conditions of the experiment, to track the number of particles detected as a function of time, to make histograms of their size (granulometric spectrum) and to visualize the recorded data points for a possible extra data analysis.



The power dissipated by the components of the board and on the sensor chip produces a temperature increase of only 10°C, mainly concentrated on the smaller board that houses the sensor chip.
The system demonstrated to be insensitive to ambient light (less than 10bins variation between sensor exposed to laboratory light or covered by a black tissue). Also with a desk light directed toward the sensor, the output signal variation remains within 60 bins, to be compared with the 8um PM signal of about 700 bins, and therefore not affecting the counts.

5. Conclusion

The project results in a fully electronic system for real-time monitoring of the dust particles deposited on the surface of its sensor chip. The success of the project adds a new operating device to the one currently used for airborne dust detection. The peculiar features of the system in terms of performance, i.e. particle size resolution (from 1 to 15micron in diameter, with S/N>20 over all diameter spectrum), very small physical size (27x30.5x10mm^3), portability (needs only an external 5V power supply), robustness (no fragile parts except the sensor chip), connectivity (USB/Bluetooth) and real-time detection (time resolution of less than 1s) and traceability (all events are recorded in amplitude and time in a local memory card for experiments lasting several weeks) result in a very innovative device for the space sector as covered by ESA.

Thanks to miniaturization, local dust particle monitoring will be possible during subsystems fabrication, during assembly of the payload, in the launch phase, as well as over use in long duration missions. The fully electronic detection, processing and transmission of dust data makes the system ready for a possible network of interconnected sensors, to target situations where the time information of correlated dust events in distant sites is scientifically interesting.

6. Future Work

The system is very flexible, and its characteristics can be further improved and adapted to the actual needs envisaged in a specific space application. For example, and in particular, the chip can be tailored in its active surface to any shape and size, to target different ranges of the dust particle dimensions and to better adapt to the site of the measurement. This would be extremely attractive in those cases where the dust diameter range is known and different from the one investigated so far (for example from 10micron to 100micron or higher as opposed to the present design that is tailored for 1micron to 15micron dust size) or the necessity to place the sensor on a specific site of the space apparatus that requires size constraints. To this goal, a new design of the sensor chip could be foreseen in which the dimension of the interdigitated electrode, the spacing between them and the overall topology would be redesigned to address that specific configuration.

A more ambitious follow-up in this research line is the monolithic integration of the sensor and the microcontroller in a single chip, presently on two separate components. This further miniaturization of the system toward a single chip apparatus would allow unprecedented flexibility in the positioning of the detector inside scientific instrumentation and/or over the surface of delicate components (mirrors, lenses, etc.) toward the realm of "semi-transparent" in-situ and real-time monitoring of dust particulate.

As the monitoring and control of airborne particulate is a subject of interest in many scientific, industrial and service activities, far beyond the space sector, a connection with industrial companies could be interesting in the longer term to realistically foresee any further industrial development that might follow from this project to higher TRL and to an industrial product with a larger production.