Integrated Airborne Particle Matter Detector

DIPARTIMENTO DI INGEGNERIA ELETTRICA ELETTRONICA E INFORMATICA
Università degli Studi di Catania
Ph.D Brainstorming Day
October 29th 2019

Ph.D Student:
U. Ferlito

University Tutor:
Ing. Prof. A.D. Grasso

Company Tutors:
- *Ing. M. Vaiana*
- *Ing. G.Bruno*

life.augmented
STMicroelectronics, Catania, Italy

Abstract

The project aims to the development of a miniaturized atmospheric particulate matter sensor. The detector relies on a gravimetric selection of the particle size and on an integrated capacitive sensing interface. In this communication, in particular, preliminary results regarding two different electronic readouts are presented.

Motivation

Atmospheric particulate matter (PM) is a category of airborne pollutants that includes dust, tobacco smoke, diesel exhaust, and other primary sources. Fine particles that have a diameter of 10μm (PM10) and 2.5μm (PM2.5) represent a threat for human health because of their ability to penetrate deep into the respiratory system. Indeed, exposure to PM10 and PM2.5 has been linked to a reduction of the life expectancy between 8 and 36 months. Conventional methods to monitor PM concentration are based on gravimetric or laser scattering detection methods are bulky and costly, and dot not allow appropriate spatiotemporal resolution. Recently, solutions exploiting high-resolution capacitive sensor has been proposed. However, it relies on static sensing of a particles deposited on interdigitated electrodes, thus it is not suitable for real time detection of in-flow particles, since the electrodes must be cleaned after every measurement. In this work we propose an integrated airborne particle matter detector that exploits capacitive sensing to detect PM flowing in a channel.

Mechanical System Design

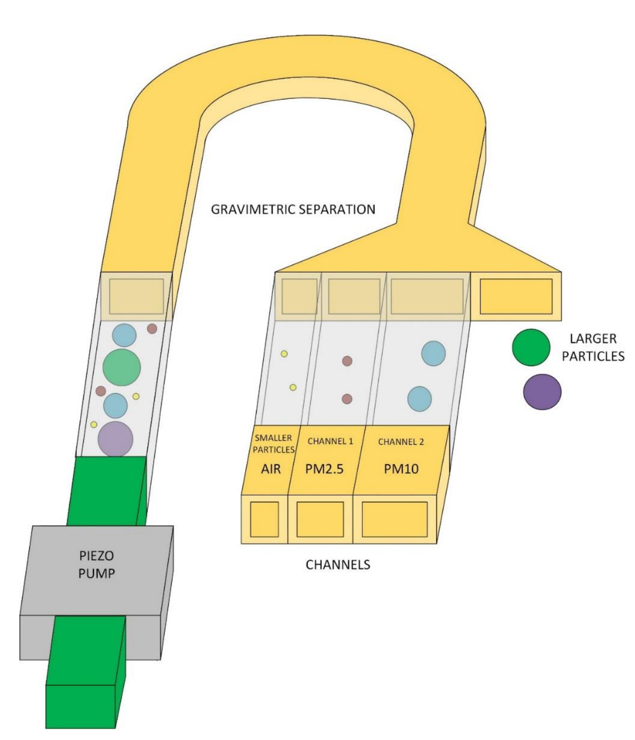

Fig. 1 - Conceptual scheme of the centrifugal-effect PM selection system

The system relies on two different sub systems. The first one is a **microfluidic channel**, that allows separating the PM according to their diameter exploiting centrifugal effect. The second sub system is the **electronic readout section** made up by three different solid-state sensing channels (one for PM10, one for PM2.5 and the last one for reference). The system exploits a silicon cap placed onto the CMOS chip. Two different configurations of the sensing electrodes (or pixels), namely parallel-plate and planar (or interdigitated).

Preliminary simulations in COMSOL reveals that the parallel-plate configuration lead to a higher capacitance variation. As an example, considering an 8-μm Teflon particle (εr=8.8) capacitance variation is lower than 10 aF for the coplanar configuration, while it is in the order of tens of atto Farad in the other configuration. However, the parallel-plate configuration requires additional steps for its implementation due to the electrode on the upper silicon cap. The sensing method briefly described has the advantage of requiring a low-linearity capacitive readout interface, since it must detect only the transition of a particle over each electrode.

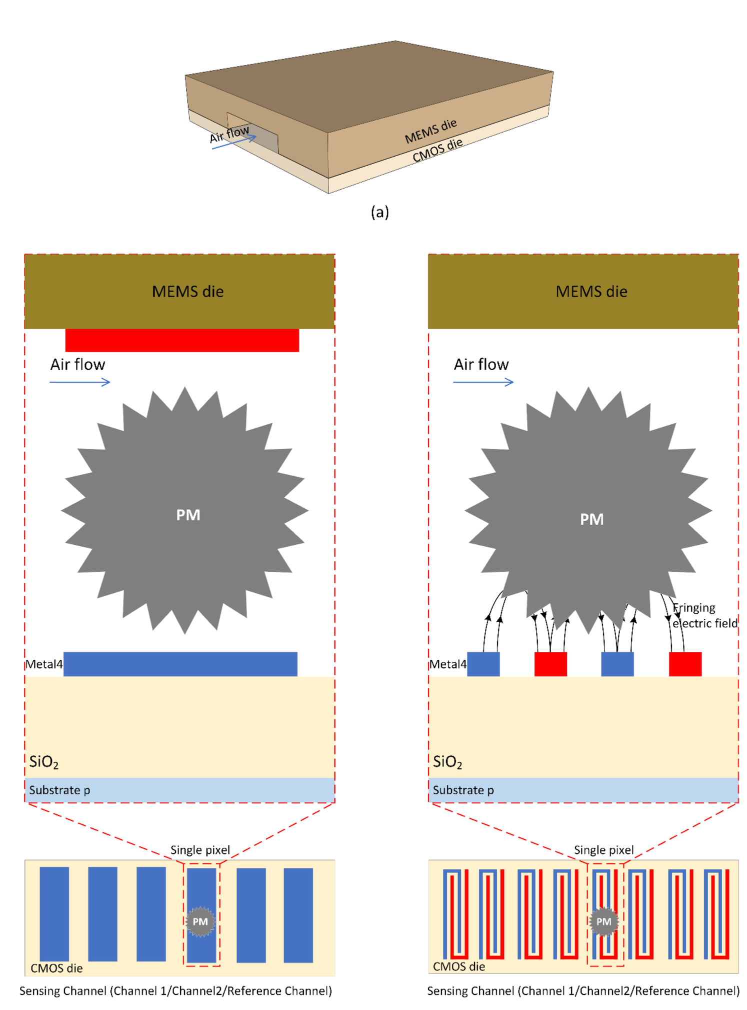

Fig. 2 – (a) 3D view of each sensing channel; configuration of the sensing electrodes (b) parallel-plate, (c) planar.

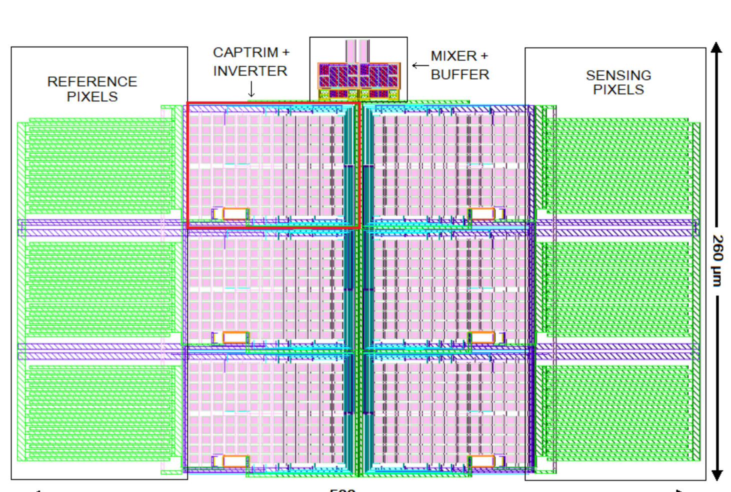

Fig. 3 – Layout of one pixel with the electronic front end (planar reference and sensing electrodes)

In Fig. 3 the layout of one pixel is shown. The part in green are the reference and sensing capacitors, while the rest is the electronic read-out block

Electronic Readout Examples

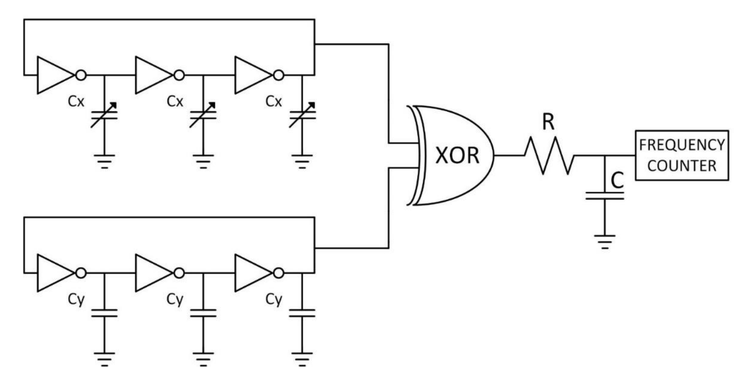

Fig. 4 – First Electronic Read-Out System Scheme

Two ring oscillators (ROs), a XOR gate and a RC filter compose the first electronic interface. The upper RO is the sensing oscillator in which the capacitance at the output of each inverter represent each pixel in the sensing channel. The second RO is the reference oscillator whose inverters are connected to the pixels inside the reference channel.

Therefore, a differential read-out is implemented to neutralize every common-mode disturbance (such as temperature and humidity variation of the air). The output signals of the two ROs are fed to a XOR gate that provides at its output their maximum common divisor in terms of frequency, or minimum common multiplier in terms of period. Considering that in one period of output signal are included M period of upper signal and N period of downer signal, the following relationship could be written, and it is the definition of the minimum common multiplier

$$T_{OUT} = M \cdot T_{UP} = N \cdot T_{DOWN}$$

The RC filter helps in cleaning the signal from the ripple and from the noise, while the frequency counter block could be implemented using a simple microcontroller.

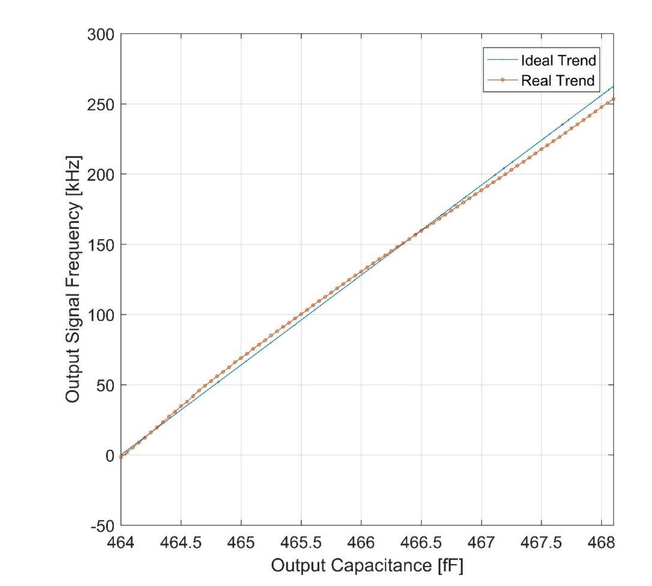

Fig. 5 – Linear Transcharacteristics of the device

The relationship between frequency of the output signal and capacitance variation is almost linear. Therefore, this solution could be used not only as threshold read-out system, but also as a linear transducer. The adopted design method for each inverter and the CMOS XOR gate guarantees optimum results in terms of phase noise and matching, by proper transistor sizing. This strategy affects heavily both sensitivity and minimum detectable variation. Indeed, the bigger is the inverter size, the bigger is the capacitance and, considering the sensitivity expression, the lower is the sensitivity.

$$\frac{\partial f}{\partial C} = -\frac{f}{C}$$

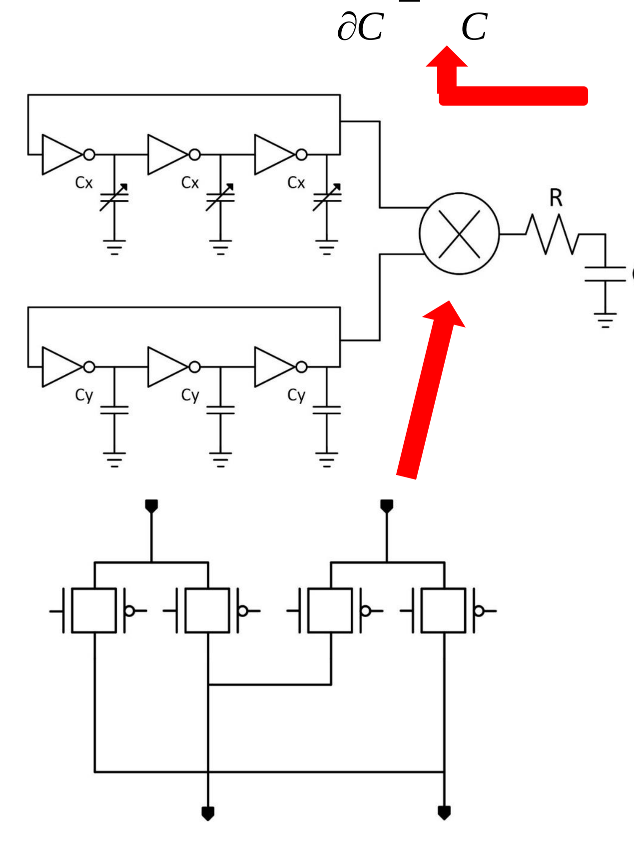

Fig. 6 – (a) Electronic Scheme of the second version, (b) Passive Mixer circuit

Montecarlo simulations in Fig. 8 reveal that the maximum common divider at the output of the XOR gate has a big spread, and moreover, due to its nature, since a certain threshold has been exceeded, the minimum common multiple variation is not linear. To get rid of this drawback, a passive mixer is adopted instead of the XOR, with the additional benefit of reducing the power consumption and of obtaining a linear trend, as shown in Fig.5. Montecarlo results also show that the variability is more or less 80 kHz in both directions. A capacitive trimming (CapTrim) circuit needs to be able to generate a capacitance variation in such a way to compensate the residual spread caused by mismatch.

CapTrim circuit in Fig. 7 is made up by nine capacitances (six driven by some switches and three useful to obtain a variation in the order of hundred of aF)

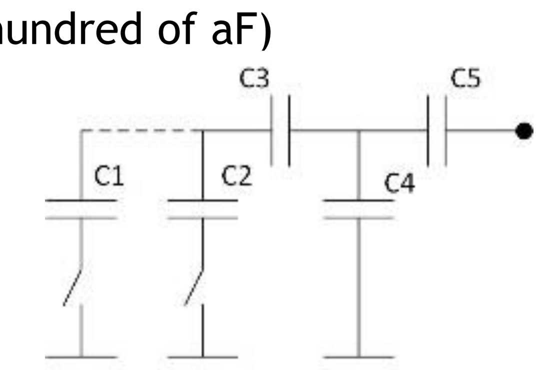

Fig. 7 – CapTrim circuit

Table I – Main parameters

Process [nm]	130
Supply [V]	1.2
Single Oscillator Frequency [MHz]	79.9
Sensitivity [kHz/fF]	64
Area [mm²]	0.15
Power Dissipation [mW]	1.37

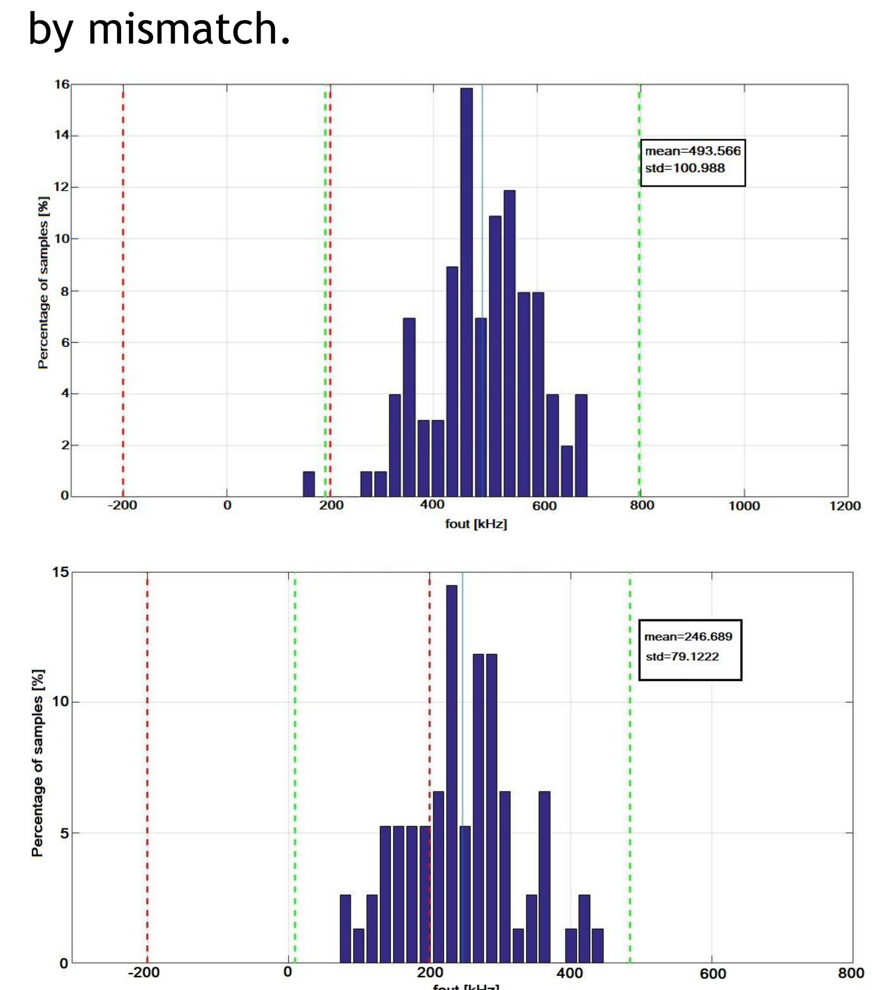

Fig. 8 –Montecarlo simulation results for: (a) first topology; (b) second topology.

Summary and Outlook

Preliminary results regarding the electronic interface of a capacitive sensor for the monitoring of air quality is presented. Simulations results have been carried out for two different circuit topologies, confirming the effectiveness of the proposed electronic system for the threshold detection of a capacitance variation in the order of tens of atto Farad. The systems exhibit good linearity performance and can hence be exploited as conventional capacitive sensors.

- U.Ferlito, A.D.Grasso, M.Vaiana, G.Bruno '*'Integrated Airborne Particule Matter Detector"* ICECS 2019