A multi-sensor Analogue Frontend using time domain signal processing

Abstract:

We live in an Internet of Things (IoT) world where our environment and vital signs are monitored by hundreds of different sensors. Each iteration of the leading Smartphones incorporate more and more sensors. A traditional multi-sensor Analogue Frontend (AFE) consists of separate channels from each sensors. Each signal path is custom designed for a particular sensor and a mux connects the individual paths to a shared ADC. This implementation takes up a lot of chip area especially if the signals need large resistors and capacitors to filter out noise above 10kHz. Analogue to Digital converters have undergone a huge increase in performance in the 21st century. These improvements have meant that the power bottleneck in sensor systems is now the analogue interface not the ADC. The circuit techniques developed in this research project will be applicable to most sensor interfaces. The project will also leverage Tyndall Sensor Technology and know-how to enable new applications in the areas such as environmental monitoring. This work is applicable to the MCCI themes of Smart Agriculture, Connected Health and Industrial.

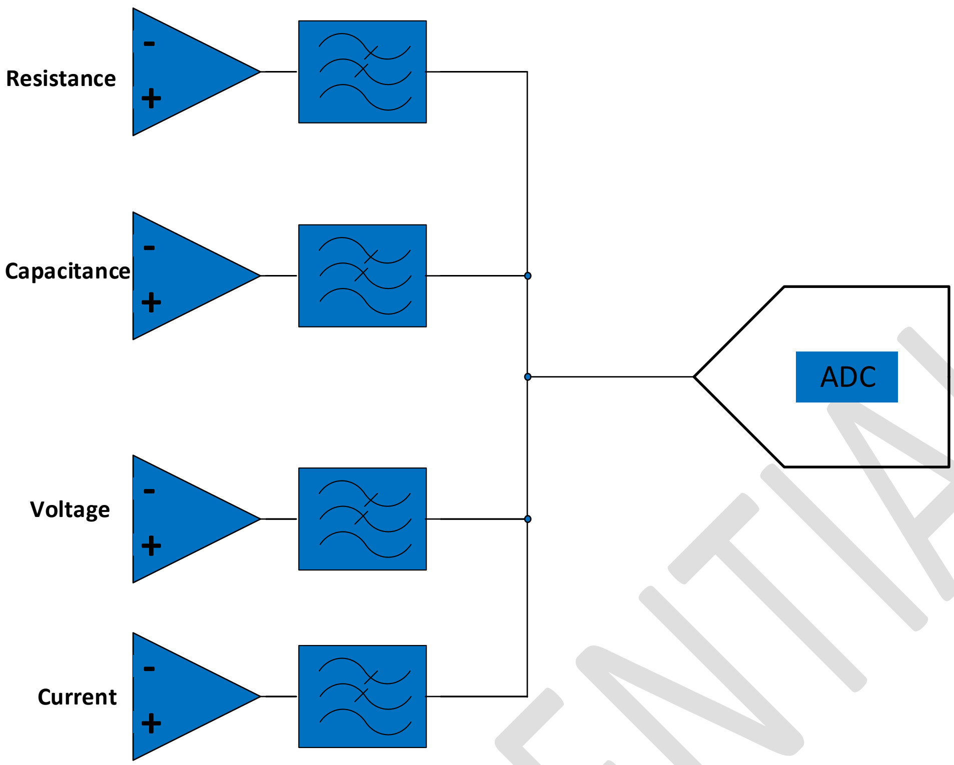
Introduction

This research project is primarily a circuits research project to design a robust adaptable sensor interface that can support Resistive, Capacitive, Voltage and Current mode sensors. A further goal will be to produce circuits that are lower in power and smaller in size than existing solutions.

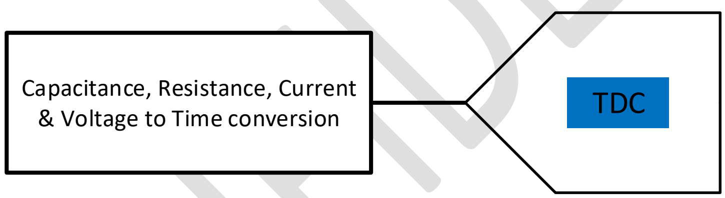
Time based signal processing uses circuit blocks such as Time to Digital Converters (TDCs), VCOs, comparators and digital logic to convert sensor signal to digital. These circuits all benefit from process scaling so the performance and power consumption will improve at advanced CMOS processes unlike conventional analog signal processing. Fig. a, on the right, shows a conventional multi-sensor AFE. The ADC is shared but each sensor path is separate. Fig. c shows a resistance to time conversion circuit with a TDC to measure it. While different sensors have different voltage and frequency ranges a goal of the project will be to share circuitry between different resistive, capacitive, voltage and current paths to produce a low area solution. Dynamic circuits and duty cycling will be employed to minimise the interface power consumption.

ADCs are only as accurate as their voltage references. Time to digital converters are only as accurate as their time references. Part of this project work will investigate low area, low power time reference circuits which can be used to calibrate the TDC circuits so absolute accuracy can be achieved by the sensor interface.

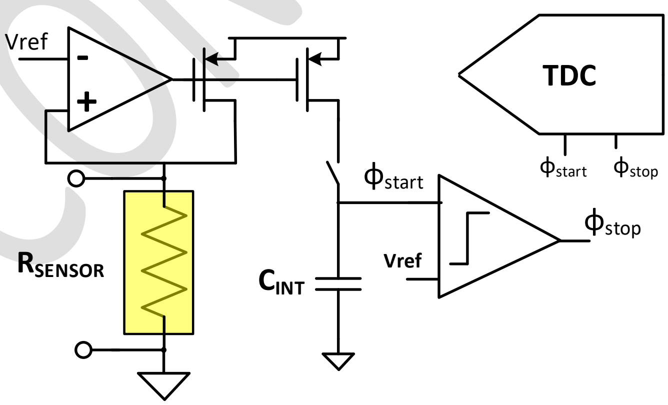
This work is under the MCCI precision circuits pillar and targets the goals of enabling analog circuits at deep sub-micron nodes and More than Moore where sensors are integrated with CMOS. While this project is concentrating on the sensor interface, future collaborative research could look at digital algorithms to infer decisions based on the sensor readings. Other projects can use the AFE techniques to solve different sensor applications such as connected health.



(a) Traditional Sensor AFE



(b) Combined Time domain Sensor AFE



(c) Example of a Resistance to time measurement

Time to Digital Converters (TDCs)

We are investigating TDCs to identify the most suitable architectures. The Flash TDC as shown in Fig. 2 have its resolution limited to the delay of an inverter and for a large dynamic range N delay stages are required. This means that both precise resolution and wide measurement range can't be achieved by this architecture. Ring Oscillator based topologies such as the Gated Ring Oscillator (GRO) [1] or Switched Ring Oscillator (SRO) [2] are promising topologies allowing counters and ring oscillators to be combined. It is currently under investigation if quantisation noise shaping TDCs are beneficial. The sensor signal needs to be converted into a pulse and then digitized by the TDC, we need to investigate if an oversampled ADC will require many extra pulses to be generated.

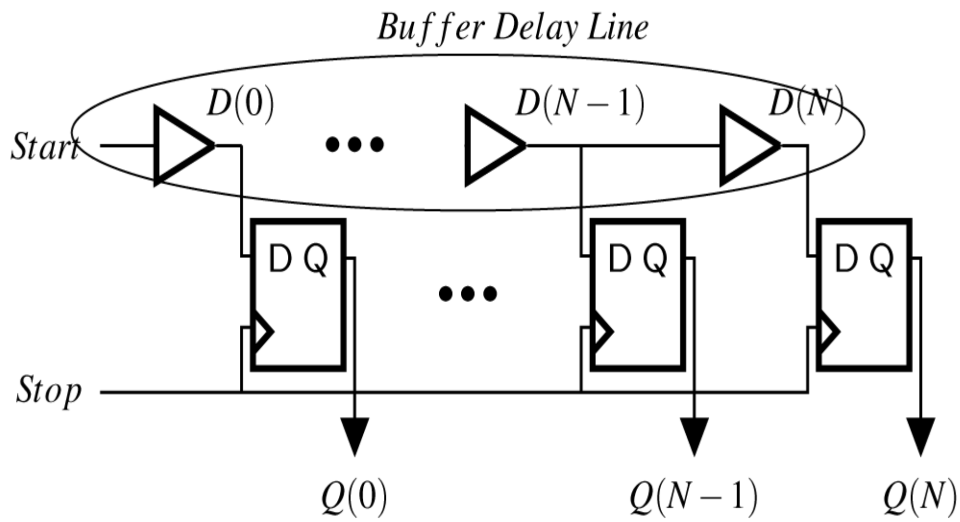


Figure 2: Tapped delay line TDC

Application:

Suitable applications for our multi-sensor analog interface are under investigation. A room air quality monitoring chip is an interesting application. Temperature, Humidity, Gas Sensors and Passive Infra-Red could be measured as shown in Fig. 3. We are currently working to identify suitable gas sensors. Resistive MOX gas sensors which can cater for a wide range of gas types have limited selectivity and need to be heated which makes them unsuitable for low power applications. Table 1 shows a high level summary of different gas sensor types.

References

[1] M. Z. Straayer and M. H. Perrott, "A Multi-Path Gated Ring Oscillator TDC With First-Order Noise Shaping," in *IEEE Journal of Solid-State Circuits*, vol. 44, no. 4, pp. 1089-1098, April 2009, doi: 10.1109/JSSC.2009.2014709.

[2] A. Elshazly, S. Rao, B. Young and P. K. Hanumolu, "A Noise-Shaping Time-to-Digital Converter Using Switched-Ring Oscillators—Analysis, Design, and Measurement Techniques," in *IEEE Journal of Solid-State Circuits*, vol. 49, no. 5, pp. 1184-1197, May 2014, doi: 10.1109/JSSC.2014.2305651.

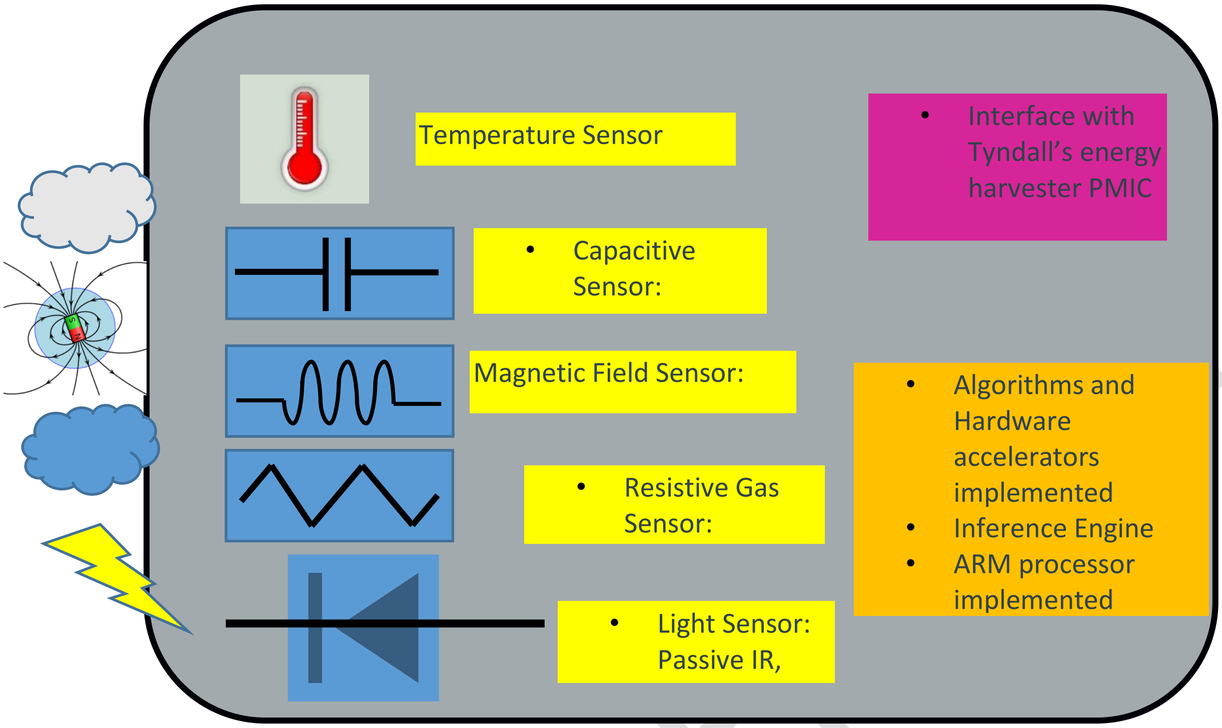


Figure 3 : Possible application for the multi-sensor interface

Sensor Type	Advantages	Dis-advantages
Infra-Red	The most reliable gas sensors for long-term. The most accurate.	There are only available for a relatively small number of target gases that give a clean absorbance in a region for which a suitable source is available.
Resistive (MOX)	Low area, they can detect a lot of different gases.	However the requirement to heat the sensor consumes a lot of power.
Electrochemical	Electrochemical sensors have the advantage of high sensitivity.	The lifetime/reliability of the sensor is a concern as the chemical reactions can change the sensor properties.
MEMS	These sensors have the advantage that they could be integrated with CMOS offering lower power and smaller area.	Limited number of groups investigating them.

Table 1: High level summary of different Gas Sensor types