A LOW-POWER WIDE-DYNAMIC RANGE READOUT IC FOR BREATH ANALYZER SYSTEM

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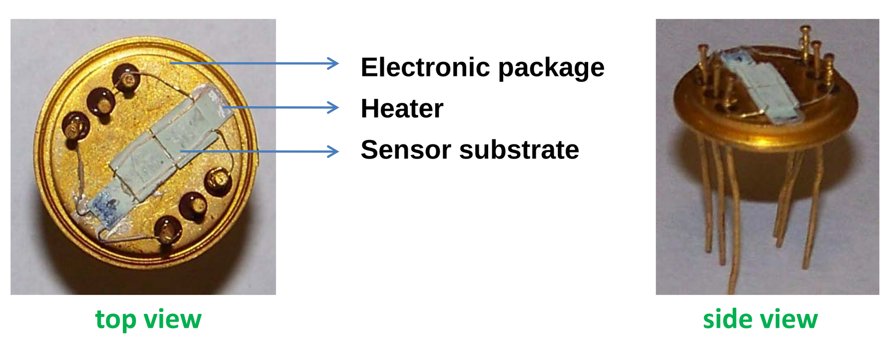
Background and Introduction

Task: detection and discrimination of signaling metabolites (disease markers) in a complex fluid, as is exhaled breath, and their measurement in trace concentrations.

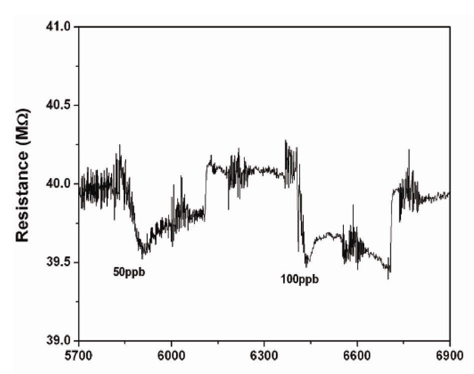
Measuring the low concentrations of analyte molecules in breath is a major challenge, along with the specificity to a given gaseous chemical.

Objective: to develop a stand-alone selective chemical detection sensor array micro-system that would operate as a robust and reliable personal breath analyzer.

By controlling the microstructure of nanocrystalline metal oxide films of the sensor so as to employ oxide polymorph phases that are sensitive to only a specific class of gaseous analytes or even be specific to a single species have been derived. Selective NO, ammonia, and acetone breath analyzer prototypes have been produced.



Sensor and heater assembly.



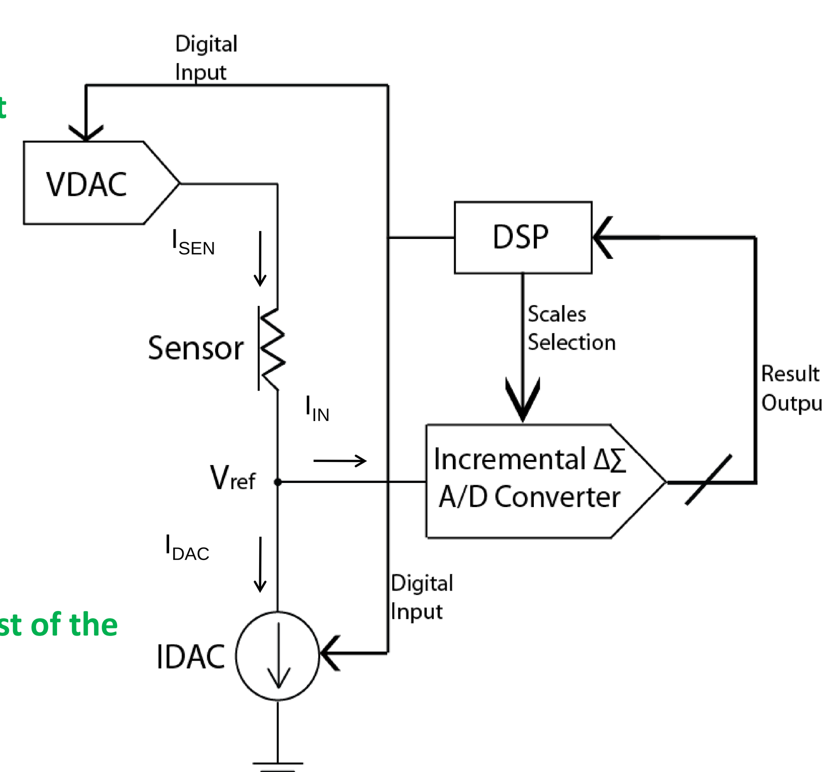
Sensing response of M_oO_3 sensor to NH_3 (50ppb and 100ppb).

Readout techniques are required to address inherent properties of the sensor, particularly:

- their large baseline resistance that can be few orders of magnitude higher than the actual sensor response
- large variability of base resistance across sensors
- the drift in base resistance over time at a different rate across sensors.

Readout System Architecture

VDAC provides adaptable current through a sensor for different base resistance, R_b.



IDAC provides path for most of the sensor current.

Block diagram of the readout circuit

Sensor baseline resistance range: 1kΩ ~ 100MΩ

0.05% ~ 10% of sensor resistance change detectable

Total dynamic range: 166dB

VDAC and IDAC compensate for the wide variation range of the baseline resistance. ADC tracks the change in sensor resistance with a change in gas concentration. As most of the sensor current from the baseline resistance is compensated by IDAC, the required resolution of the current ADC is significantly reduced. By adjusting the digital input value of the two D/A converters, the interface circuit can be both power effective and highly accurate.

Circuit Implementation

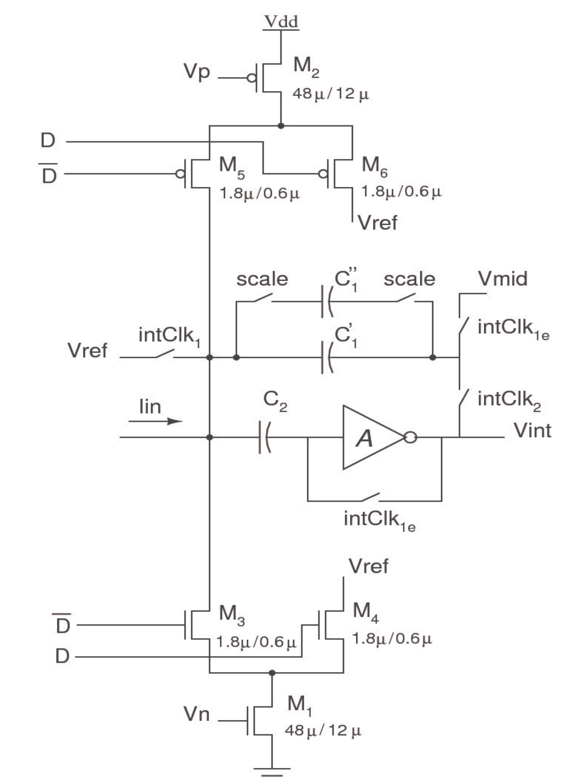
A. Incremental ΔΣ ADC

The delta-sigma ADC used in the system comprises a current integrator, comparator and switched-current single-bit D/A converter.

The ADC has two scales, selected by C_1' and C_1'' according to the input current range.

The ADC achieves 13 bit resolution.

The sampling frequency of the ADC is set to 100 Hz, which corresponds to the low-changing gas detection environment.



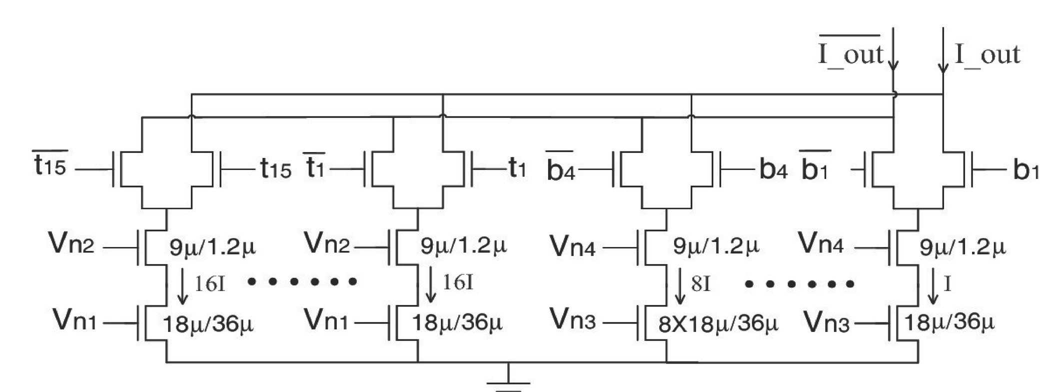
Schematic of delta-sigma current integrator

B. Segmented current-steering DAC

The 8 bit current mode D/A converter of the system is implemented using segmented current-steering structure.

4 more-significant bits use thermometer code to guaranteed monotonicity, good differential nonlinearity and very low glitches.

4 less-significant bits use binary-weighted to consume less area and reduce power.



Schematic of current mode D/A converter

System Operation

In order to measure the sensor resistance, the gas-sensing system has two phases of operation.

Calibration phase:

Digital logic decides the digital inputs of the two DACs according to a predesigned matching algorithm to guarantee the input current of ADC is smaller than the LSB of IDAC and eliminate the measurement error caused by the baseline resistor deviation as well.

Measurement phase:

The sensor resistance changes due to the concentration of the gas of interest and all of the current variation is measured by the ADC.

This circuit purely measures the current difference between the two stages, thus it is much easier to achieve high precision with a less complicated ADC compared with a single ADC design.

Simulation Results

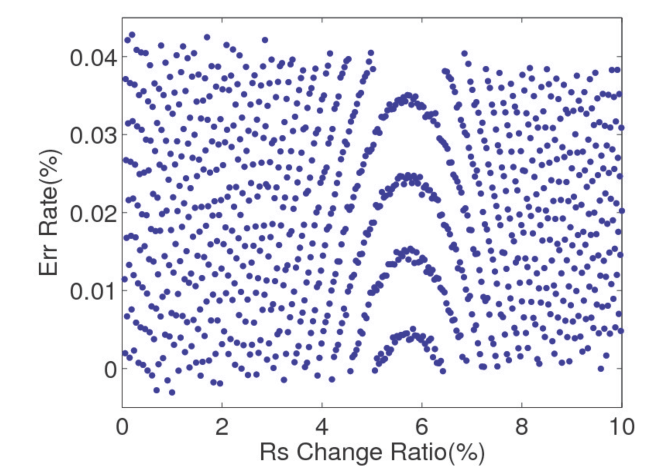
A. System Sensitivity Simulation

Sensor resistance change ratio: 0.05% ~ 10%

Baseline resistance:100MΩ

Smallest input current

Error rate < 0.045%



Error of ADC as a function of the sensor resistance changes

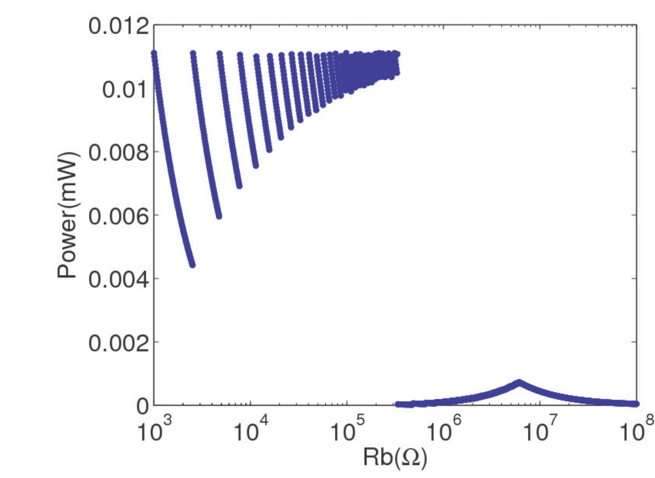
B. Power Consumption Simulation

Sensor resistance change ratio: 10%

Baseline resistance: 1KΩ~100MΩ

Largest current variation

Maximum Power: 113μW



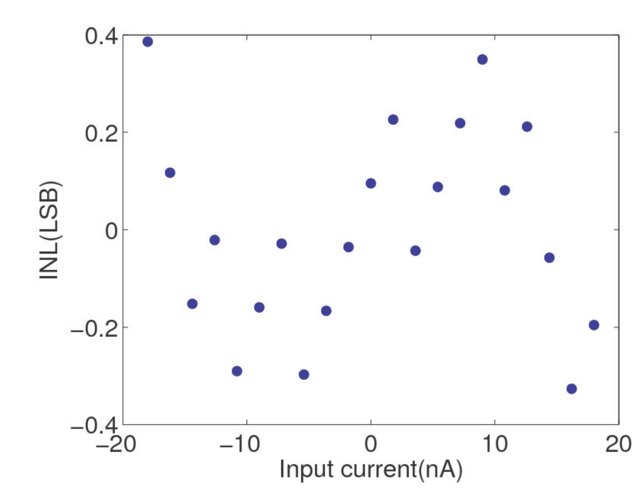
Power consumption of the readout system as the function of the baseline resistance

C. ADC Simulation

Input current range: ±18nA

I_{lsb} = 9pA

Integral Non-linearity < ±0.4LSB

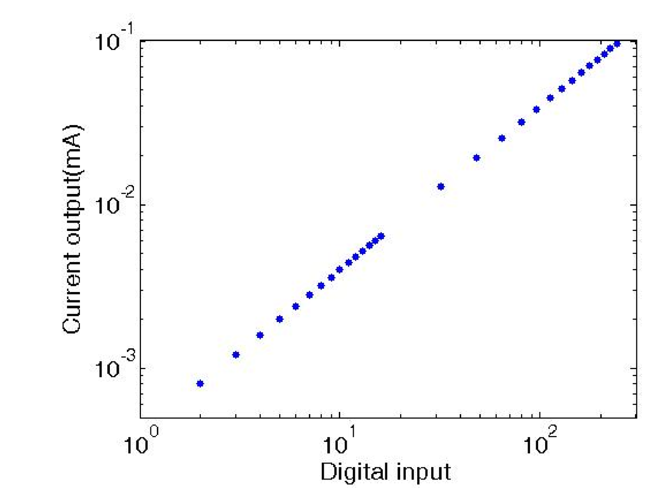


Integral nonlinearity (INL) of current ΔΣ ADC

D. DAC Simulation

Input range: 100uA

I_{lsb} = 400nA



Current mode D/A converter output linearity

Conclusion

The designed interface circuit compensates for the variation in the baseline resistance of the gas sensor and guarantees error rate less than 0.045% at the power consumption on the order of 100μW.

The implemented readout ASIC that interfaces an array of nanosensors will be integrated in a nitric oxide (NO) breath analyzer for monitoring and managing airway diseases, such as asthma.

The proposed breath analyzer technology may also be used as a coarse diagnostic tool to enable an early detection and to direct more complex diagnostic tools where to focus attention.

References

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Acknowledgment

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