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European Network on New Sensing Technologies for Air-Pollution Control and Environmental Sustainability

PARTICULATE MATTER DETECTION BASED ON ACOUSTIC RESONATORS FOR AIR-QUALITY MONITORING*

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* **Based on IEEE Sensors conference paper presented Nov. 2013**

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Outline of Talk

- Introduction to particle sensing
- SAW resonator based sensing
- Experimental results on different particles
- Conclusions on SAWR sensing
- Further Work towards particle sensing

Introduction to Particle Sensing

Key facts related to Air Pollution are:

- ❖ Outdoor air pollution is a leading environmental cause of cancer deaths
- ❖ Total number of deaths caused by air pollution (indoor & outdoor) is ca. 6.3 million
- ❖ New pollution limits set for major air pollutants:
  - **PM 10, PM 2.5**, O_3, NO_2, SO_2
- ❖ Challenges continue, while significant emission reduction have been seen in several geographical areas.

(*World Health Organisation*)

Target Parameter

Hazardous Particulate Matter (PM 10, PM 2.5, UFP) in air

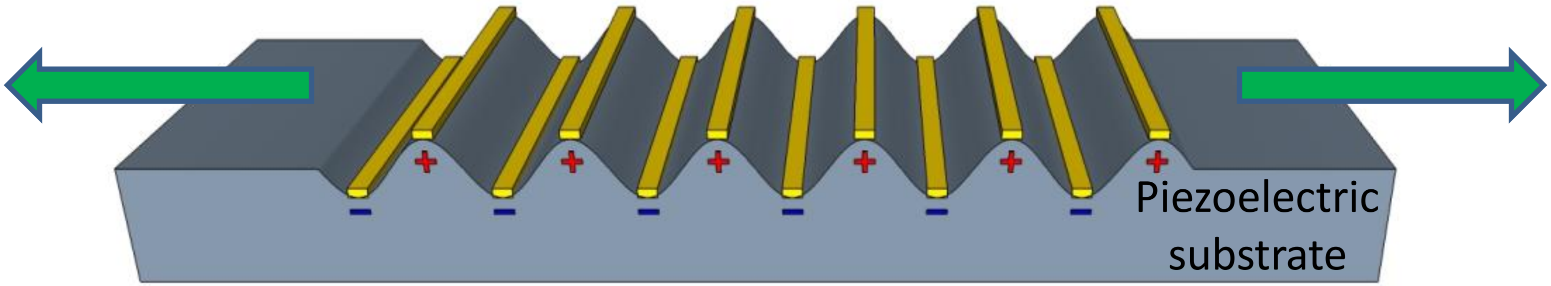
- Guidelines show that by reducing PM10 pollution from 70 to 20 ug/m^3, deaths get reduced by 15%.

There is a demand for devices enabling indoor and outdoor environmental monitoring !

Indoor (PM 2.5)   Outdoor (PM10, PM2.5, UFP)

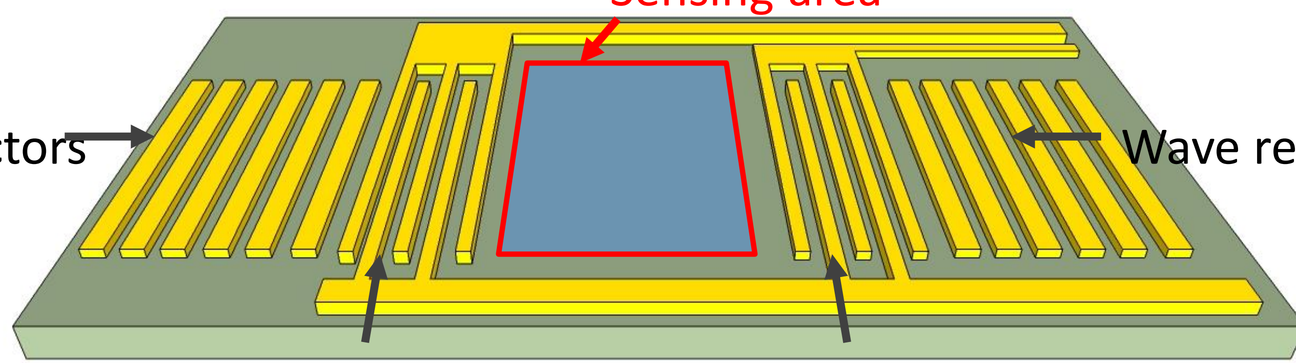
Surface acoustic wave resonator based sensing

SURFACE ACOUSTIC WAVE GENERATION USING PERIODIC ELECTRODES



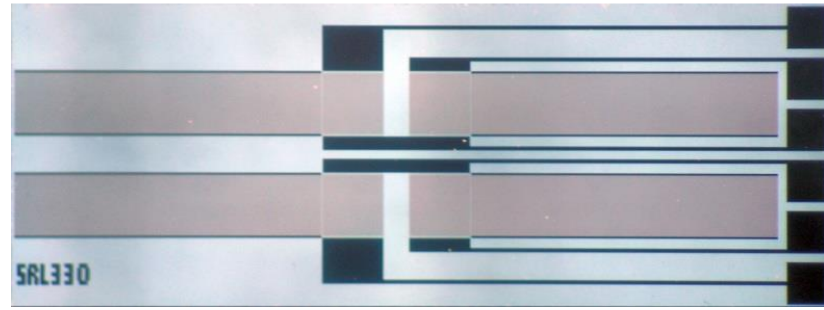
A periodic alternating potential creates acoustic surface wave

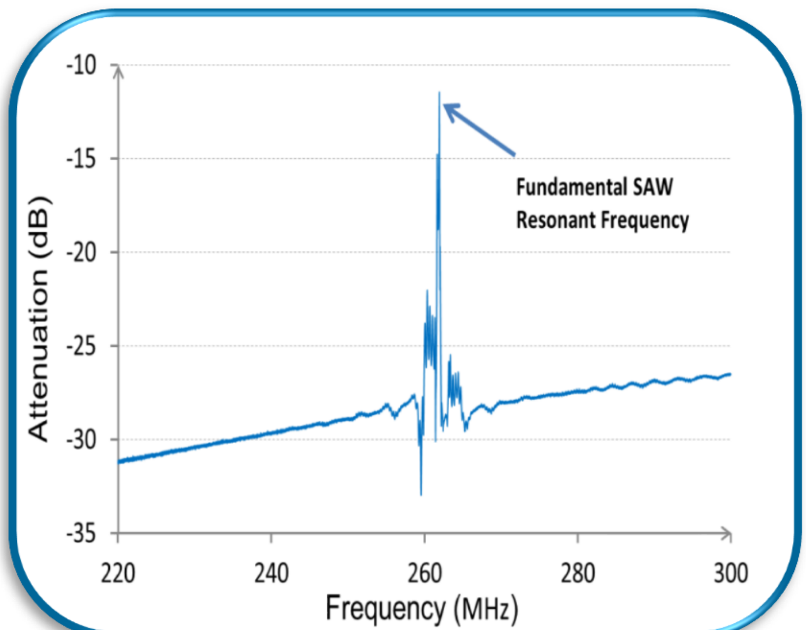
STANDING WAVE PATTERN FORMATION WITH ACOUSTIC REFLECTORS



Warwick Dual SAW Resonator at 262 MHz

- Quartz substrate/Rayleigh wave
- Al or Au electrodes
- 2-port design here
- Differential read-out to remove interference/drift

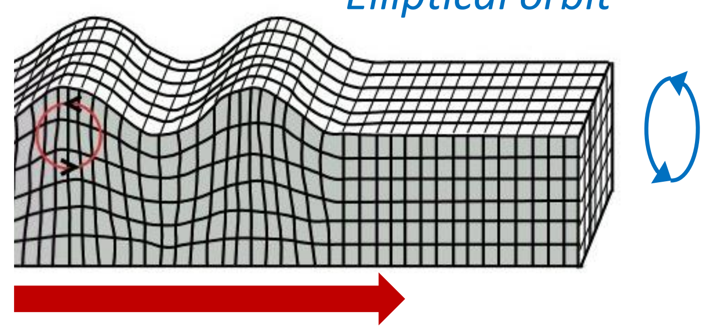




Transmission curve of 262 MHz SAWR

Rayleigh Wave

Elliptical orbit



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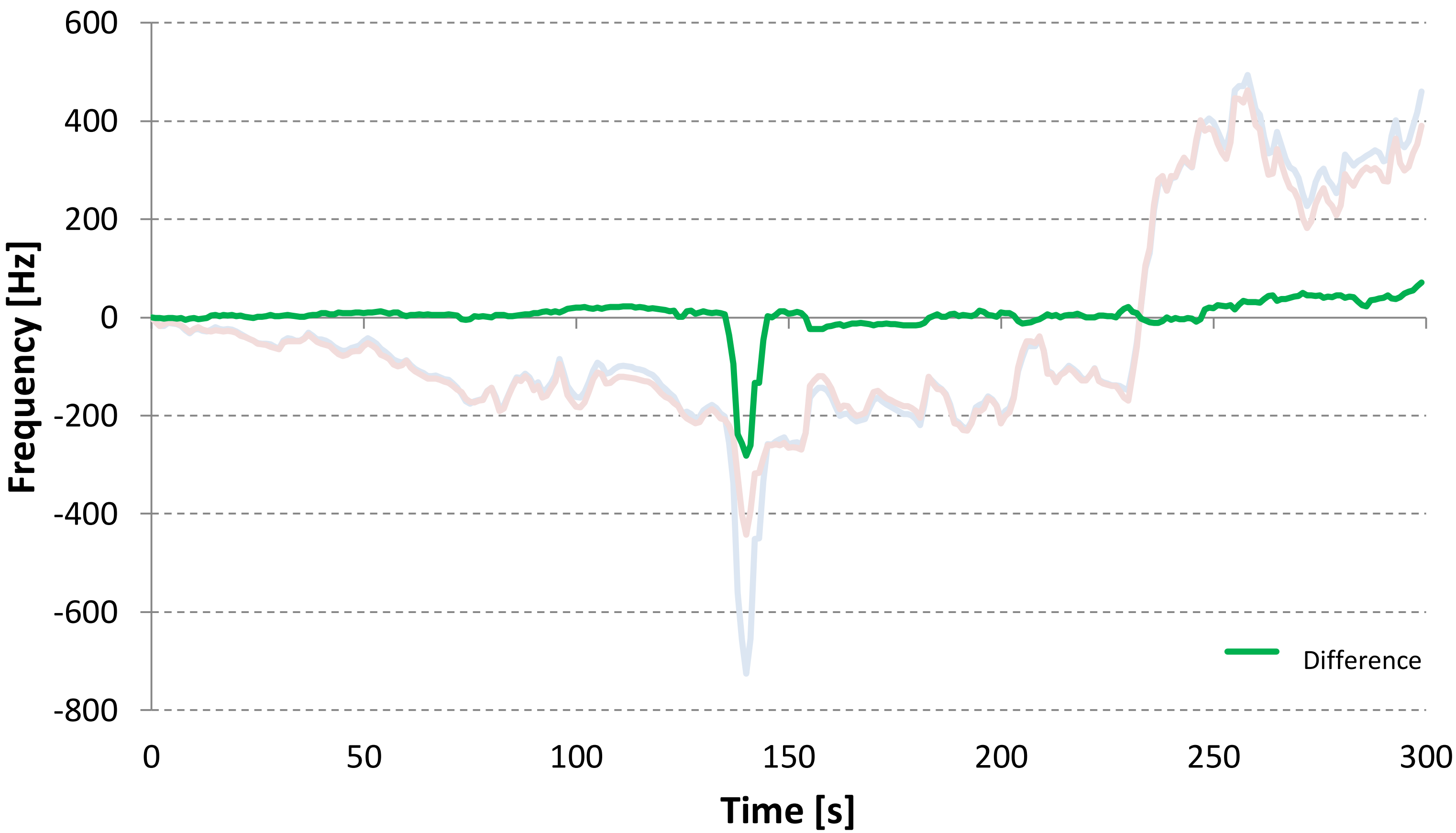
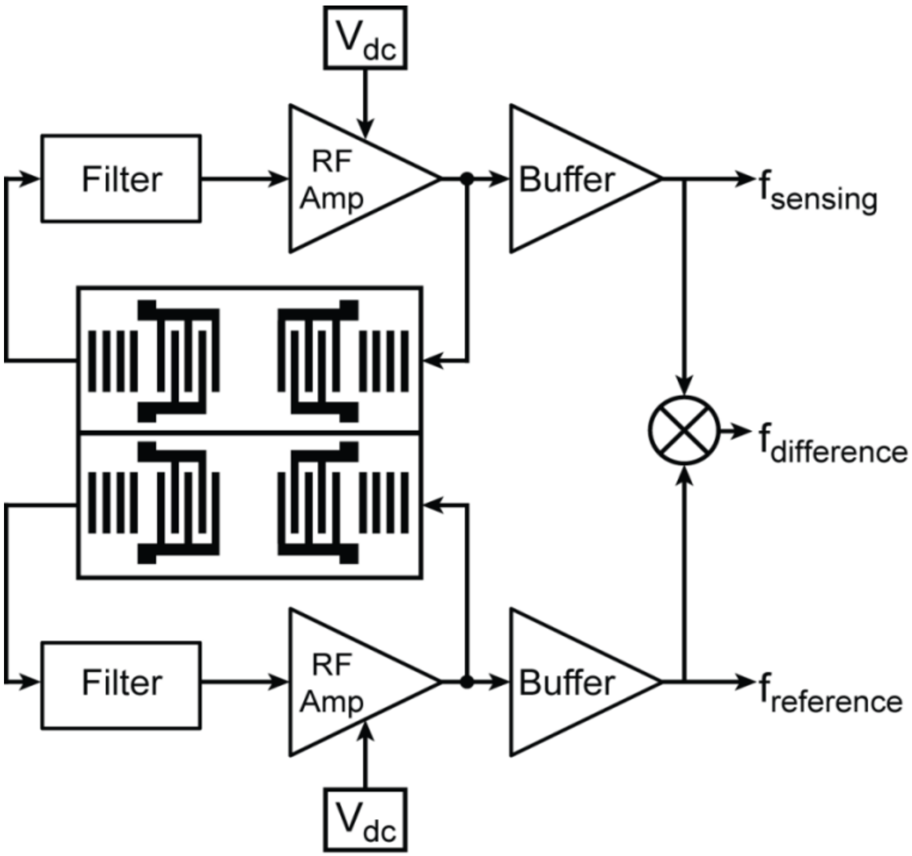
Differential signal of the SAW response



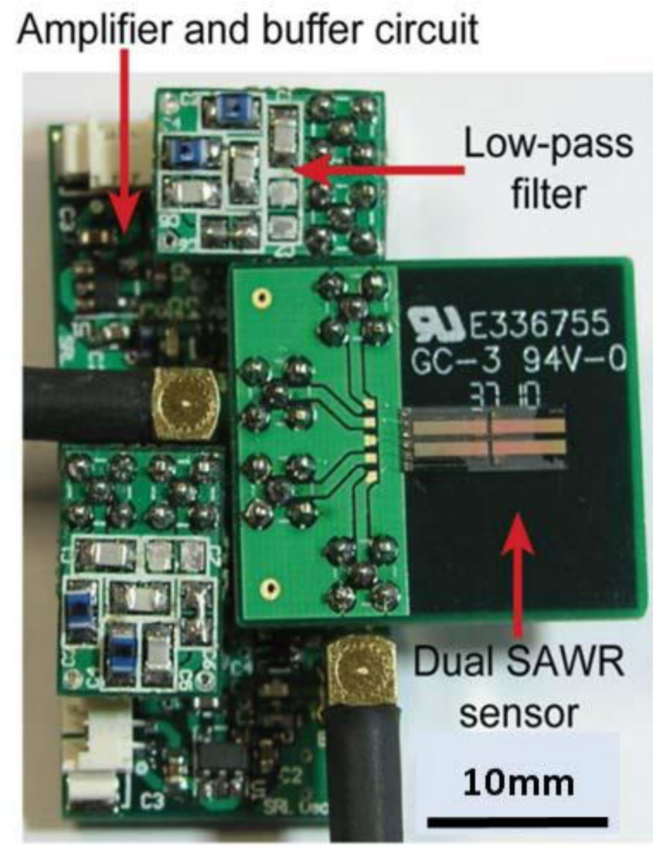
- Common mode noise is removed
- Response is purely due to the detected particular matter

262 MHz Dual SAWR Oscillator Circuit

Block Diagram of Dual SAWR

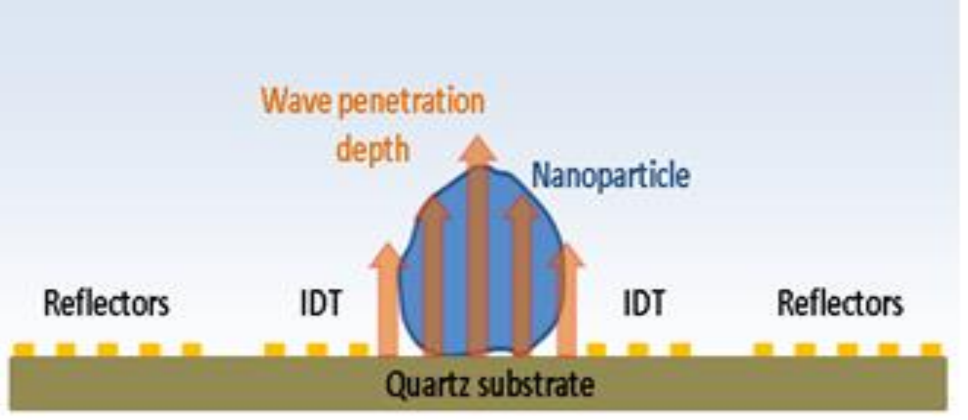


Photograph of the Dual Device



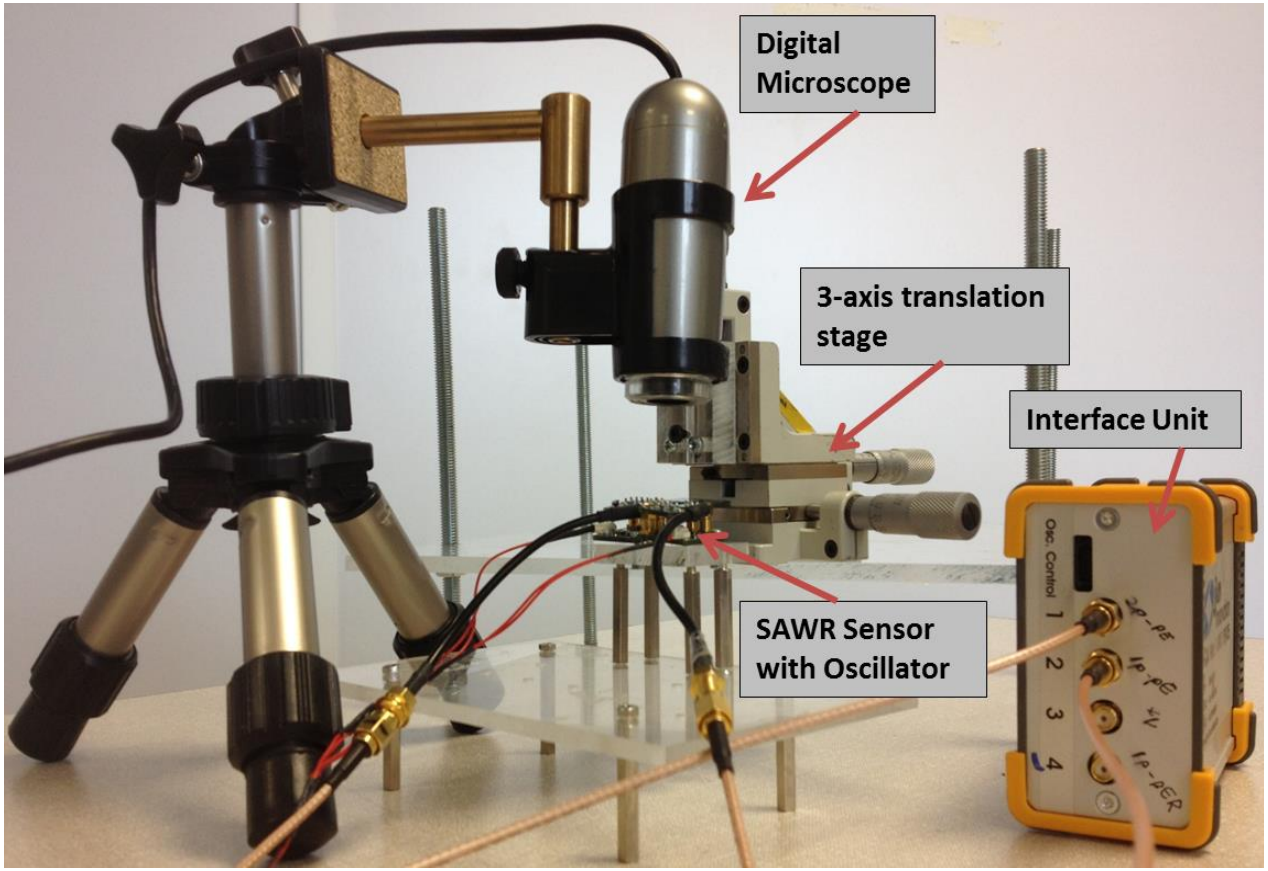
SAWR based Particle Sensing

- Penetration depth – vary according to size of particle
  - ❑ Penetration depth of SAWR inversely proportional to frequency
  - ❑ Also, mass sensitivity is dependent on operating frequency

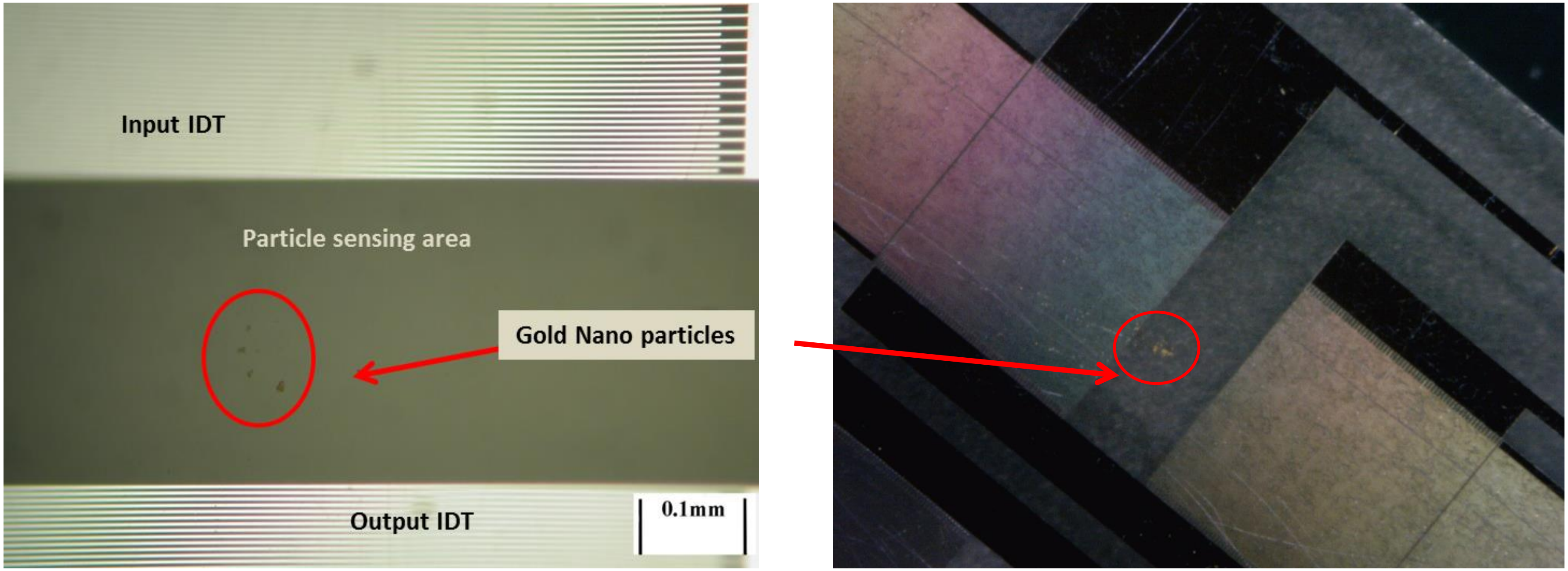


Thus, frequency dependent sensitivity tailored to particle size, allowing detection of submicron size particles

Prototype for Particulate Matter Sensing



Particles deposited on Sensing Area



Particle Type	Size (um)	Particle mass (ng)	Mass Sensitivity (Hz/ng)
Silicon	30	32	0.011
Gold	20	80	0.04
PTFE	10	1.10	4
Sucrose	6	0.044	42
Gold	0.7	0.0042	275

cost
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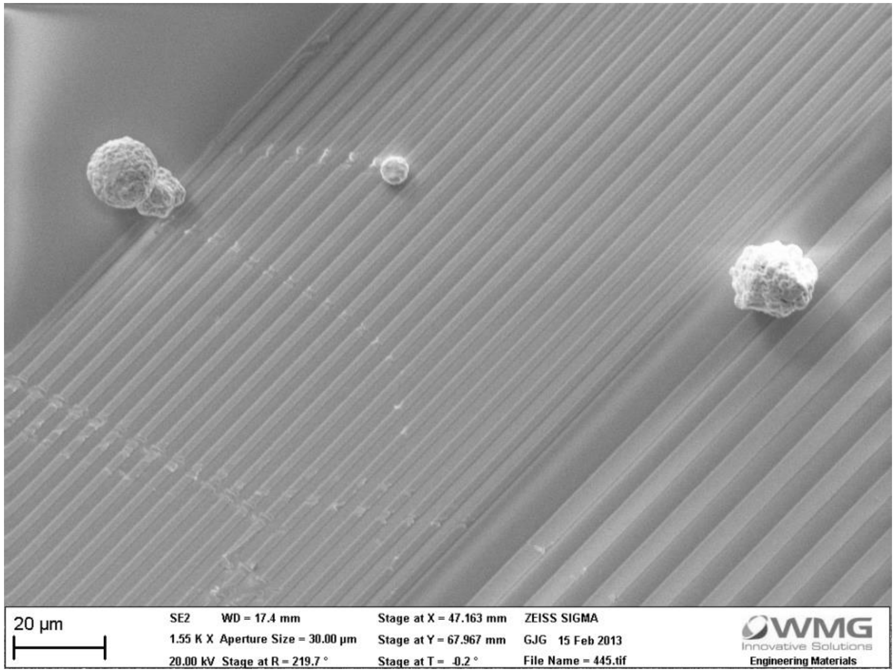
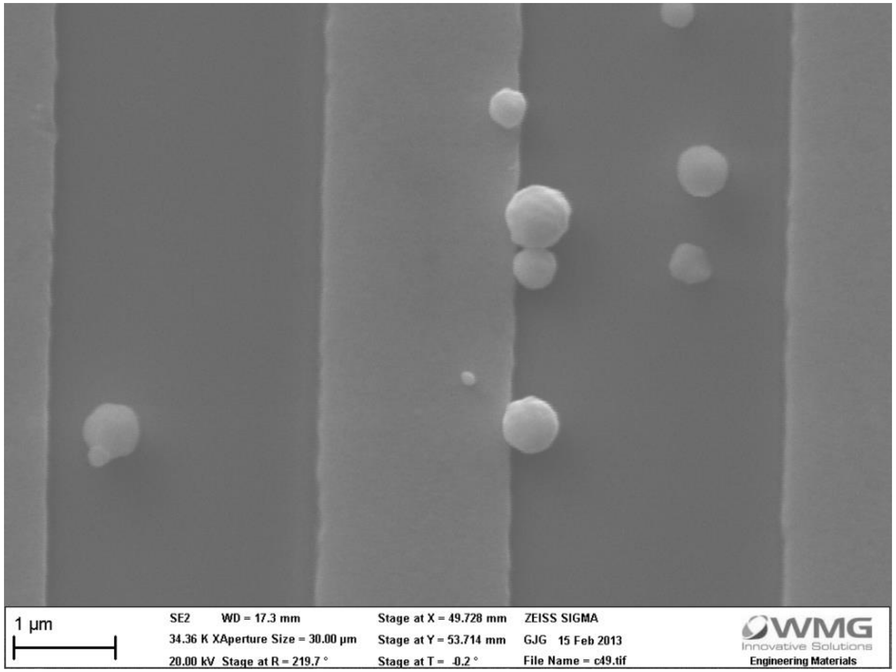
SEM images of Gold Particles

SEM Image of 20 um Gold Particles



SEM Image of 0.7 um Gold Particles



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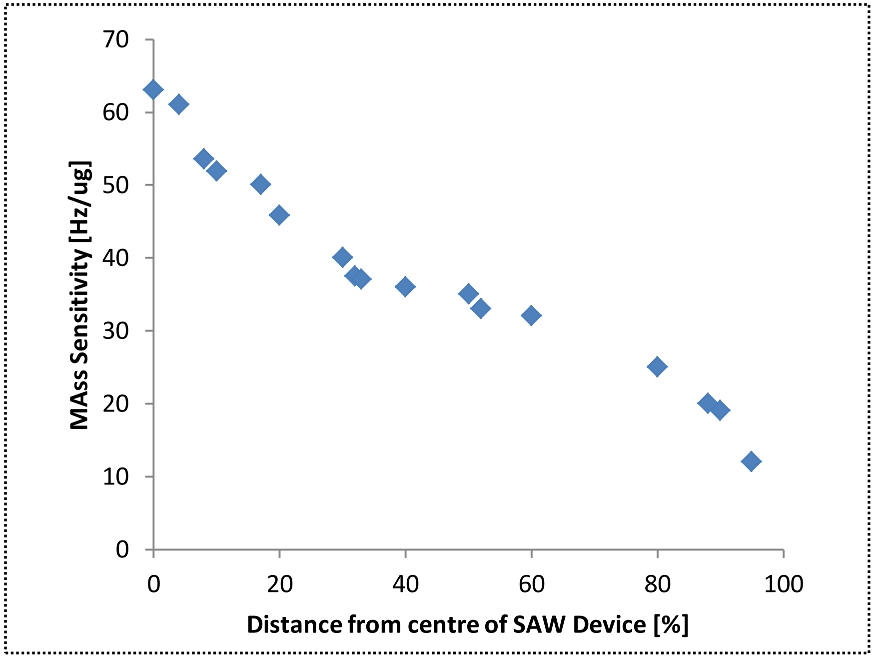
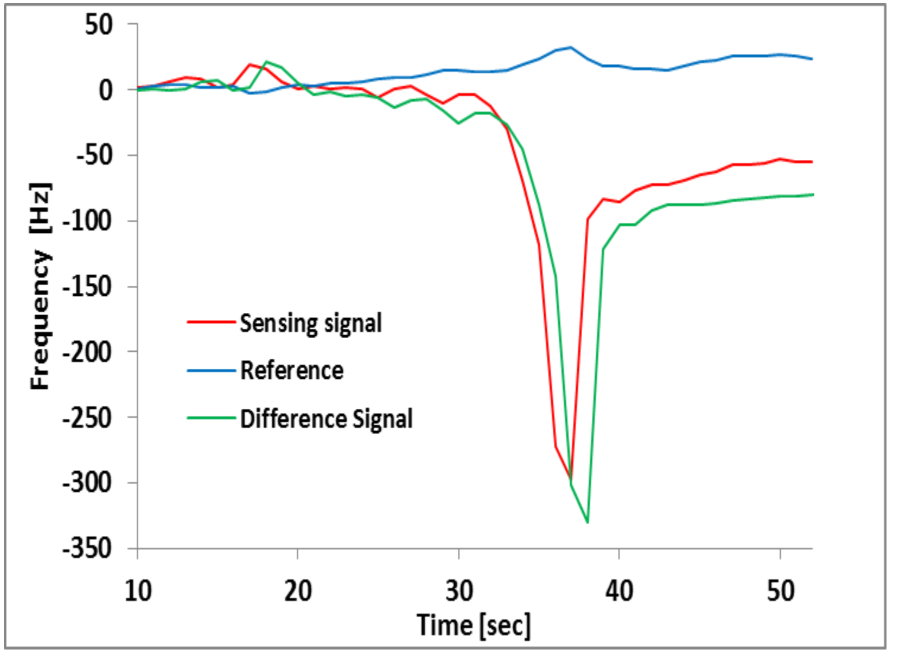
Experimental Results

- SAWR frequency response is fast
- Low-noise differential signal

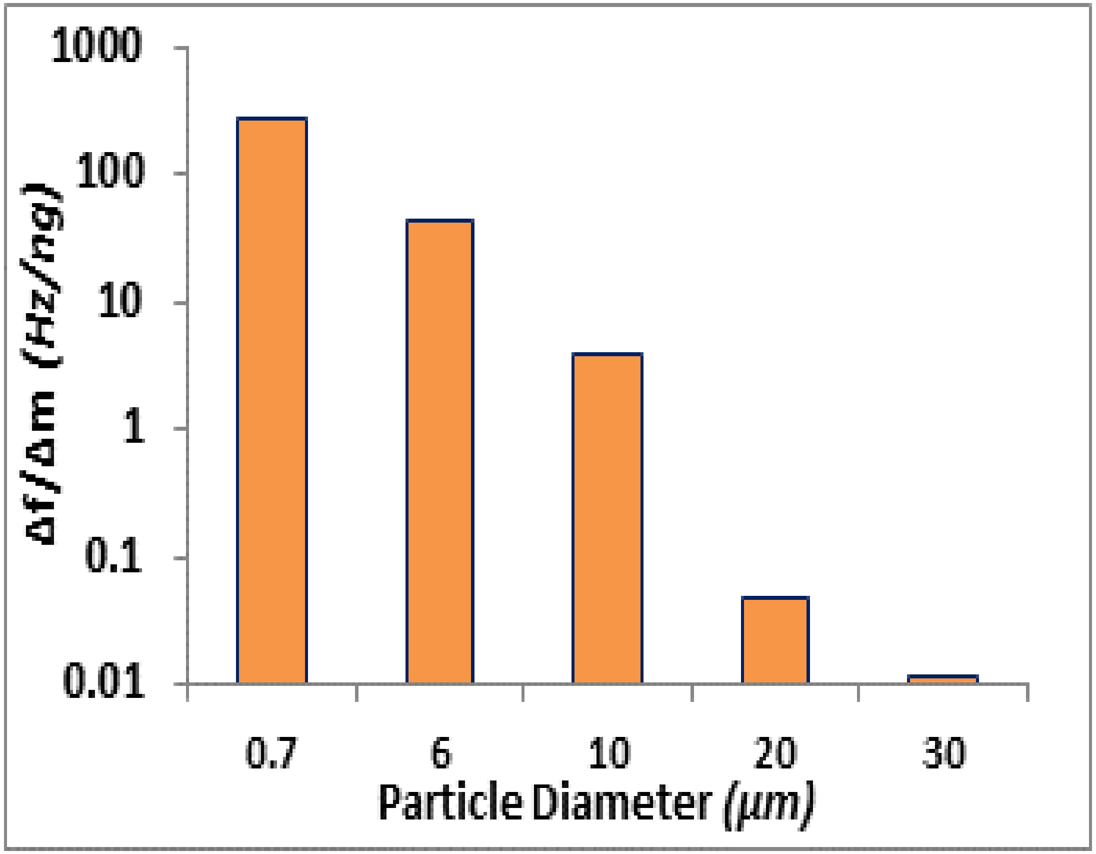
SAWR Sensitivity Analysis



SAWR differential signal



Results on Particle Sensing



- Particle size smaller than penetration depth (~4 um) exhibit higher mass sensitivity.
- Surface interactions occur in the close proximity, resulting in increased mass sensitivity

Relationship between SAWR sensitivity Δf/Δm and particle diameter for different sized particles

Conclusions

1. VOC SAWR sensors can be used to detect small particles
2. Differential measurement to remove temp. dependence
3. 262 MHz SAWR Particle sensor capable of detecting picogram change in mass (sensitivity of 4 pg/Hz)
4. Frequency dependent sensitivity can be used to size particles in micron range
5. These sensors were chosen as optimal for PM2.5 detection range

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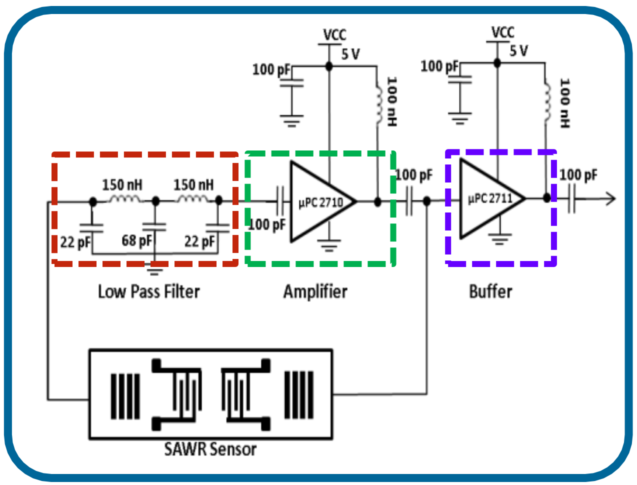
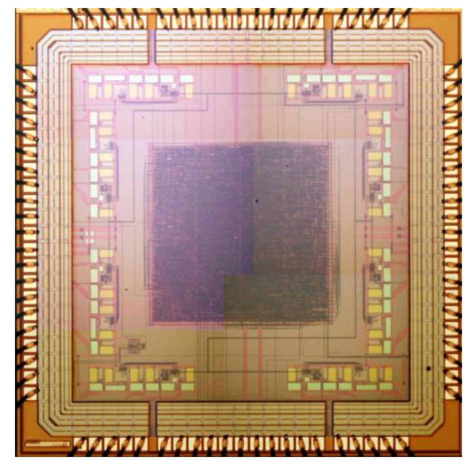
Further Work on CMOS Particle Sensors

- Develop CMOS oscillators to drive SAWRs
- Fully integrate SAWR chip for smart application
- Integrate FBAR/SMR as well (New EU project MSP)
- Consider MEMS based particle trapping and cleaning



Op-amp based 2-port SAWR circuit



Full custom RF SiGe Chip (EU iCHEM project)

Thank you for listening

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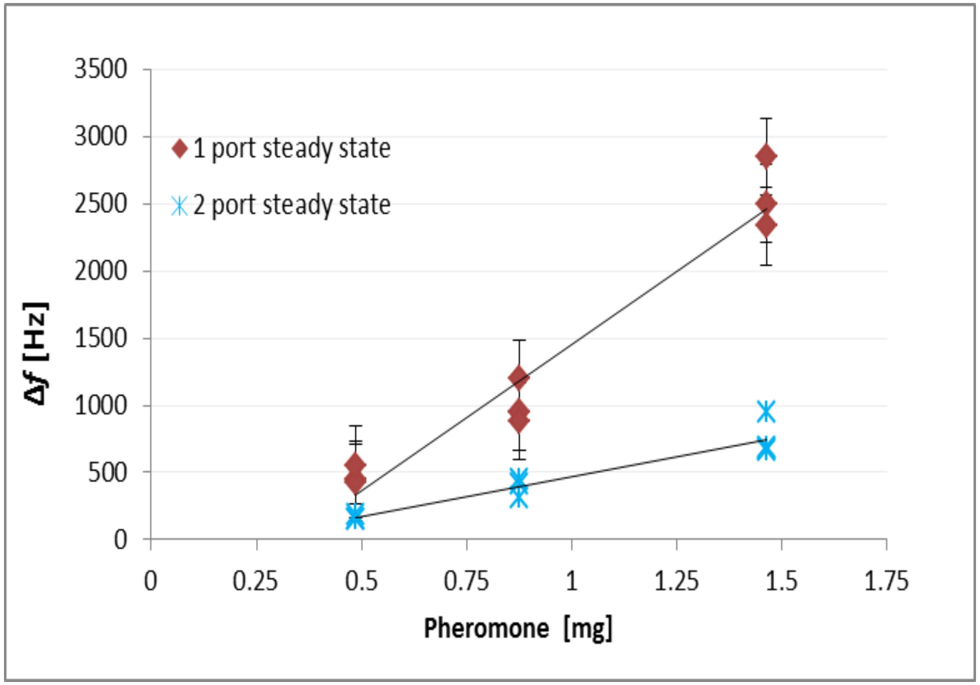
SAWR Response to Insect Pheromones in Air

1 Port Sensor vs 2 port Sensor



- Sensor response:
  - linear regime of operation
  - highly reproducible
- Pheromone used:
  Z9-14 Oac
- PPB sensitivity in air

- Superior Performance (higher response) for 1 port Colpitts oscillator

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