Sensors and actuators at NXP: bringing more than Moore to CMOS

Joost van Beek
Senior Principal Scientist
Corporate R&D, NXP Semiconductors

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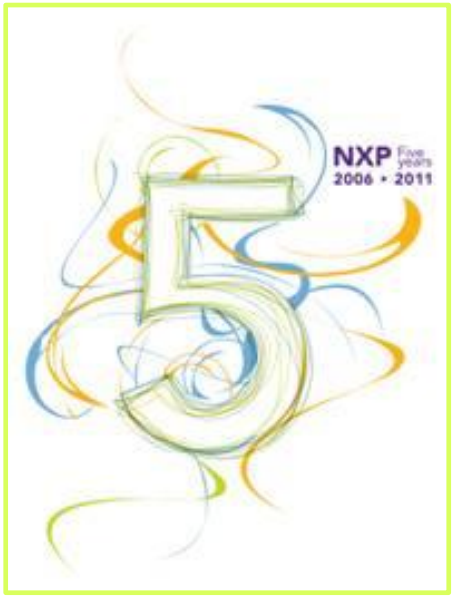
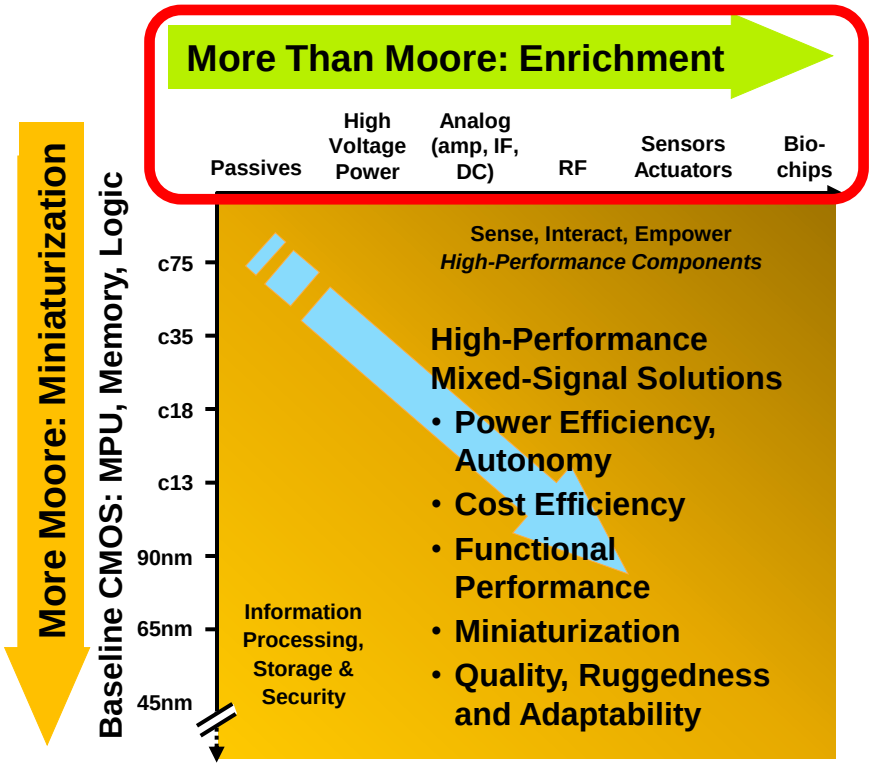
NXP Semiconductors N.V. (NASDAQ: NXPI) provides High Performance Mixed Signal and Standard Product solutions that leverage its leading RF, Analog, Power Management, Interface, Security and Digital Processing expertise.



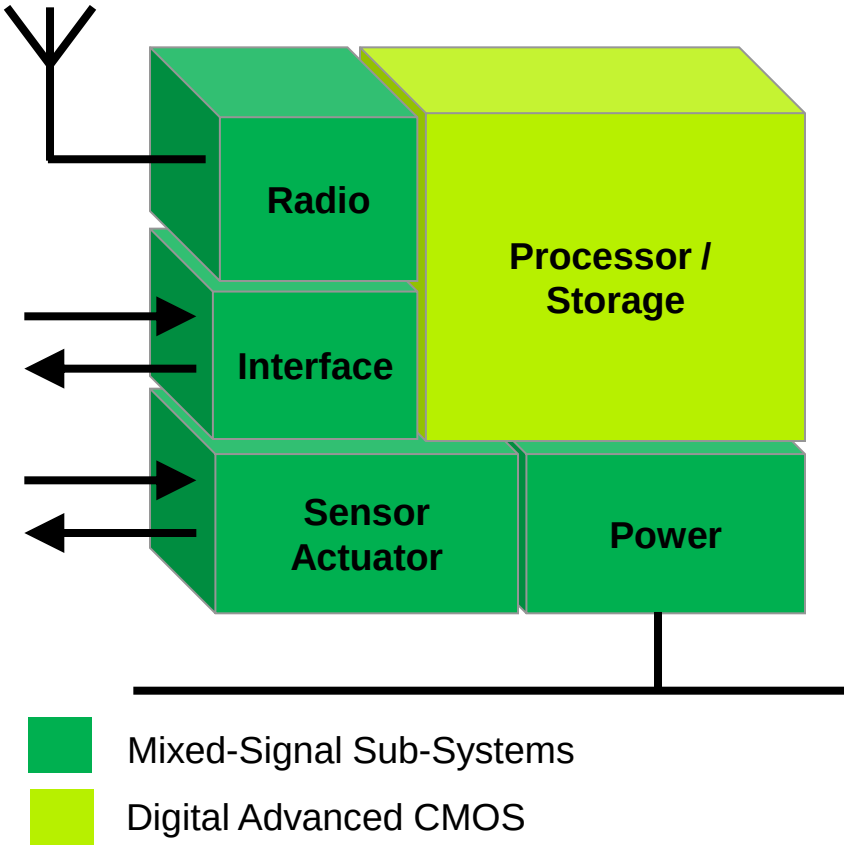
Our innovations are used in a wide range of automotive, identification, wireless infrastructure, lighting, industrial, mobile, consumer and computing applications.

High Performance Mixed Signal Solutions

More Than Moore Required



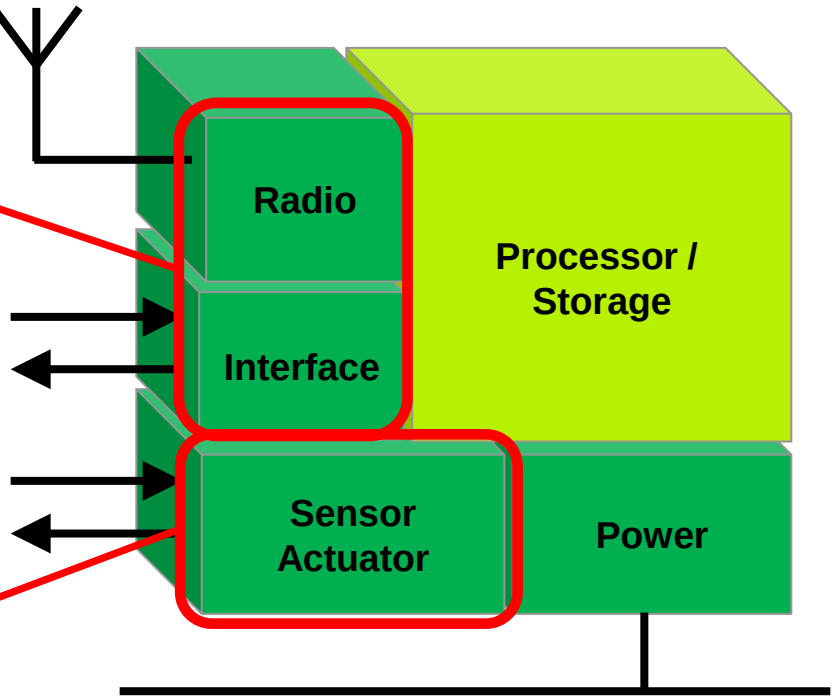
Application Optimized Mix of Analog and Digital



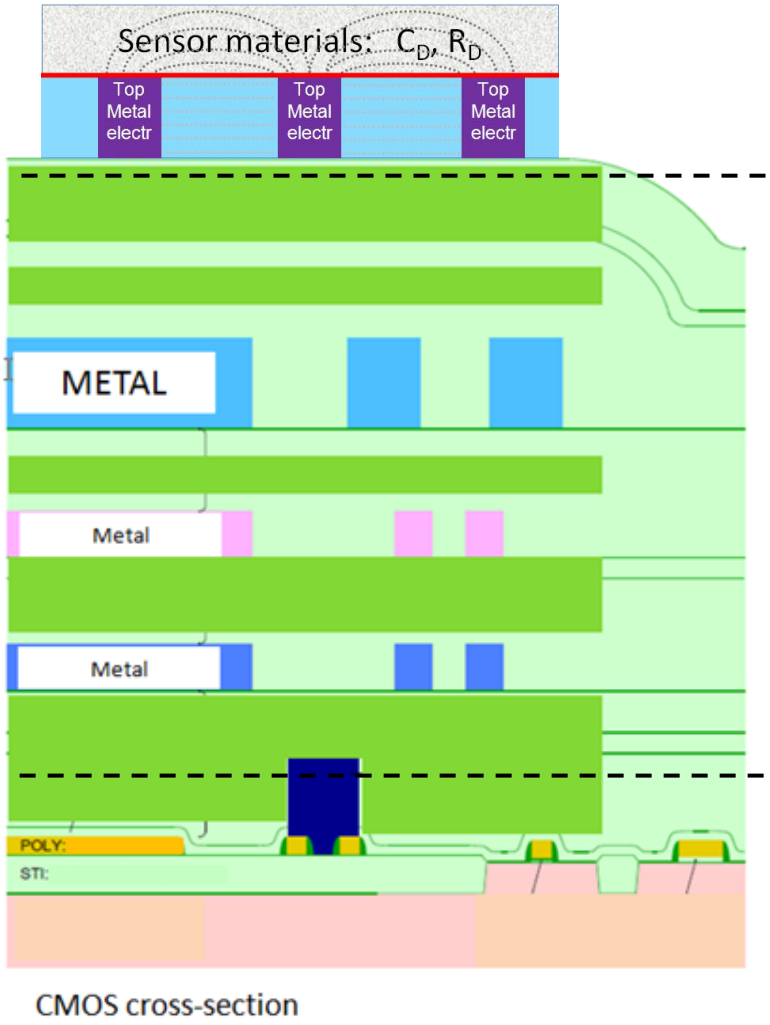
HPMS Sensor & Actuator Solutions

- Timing
- Frequency synthesis

- Humidity
- Temperature
- Acidity
- Shock
- Pressure
- Magnetic field
- Light
- CO_2



What can we do with CMOS?



CMOS cross-section

Additional layers on top of finished wafer

C/Z transducers
- RH, pH, Gas (CO2, *CO*)

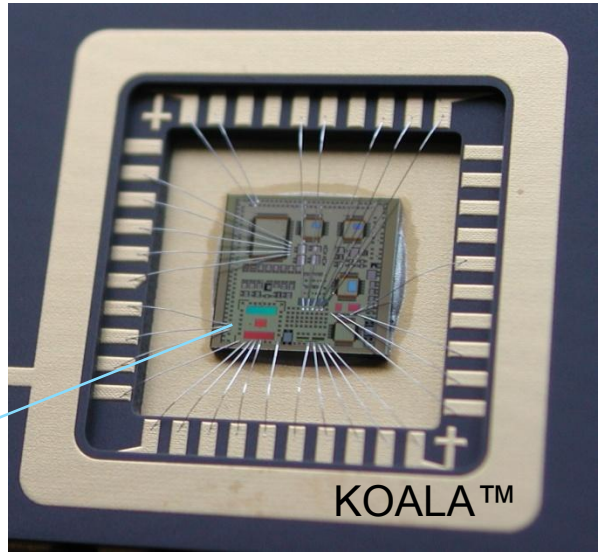
4..6 metal interconnect:
- 5.6…9µm-thick mix of Al/Ti(N)/W conductors in oxide/nitride matrix

Selective removals of materials:
-Mechanical transducers (shock, pressure)
- Thermal actuation and sensing (pH; CO2)

active devices level:
- diodes, mosfet's, bipolars

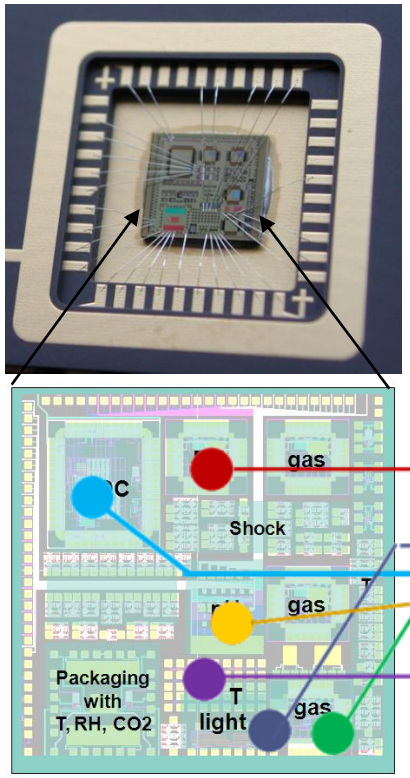
Si electronic properties:
- Eg(T) (T transducer)
- photoconductivity (ALS)

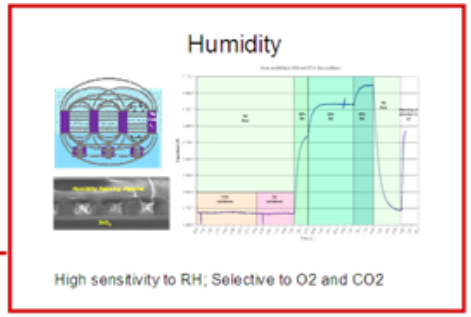
CMOS multiple sensor integration

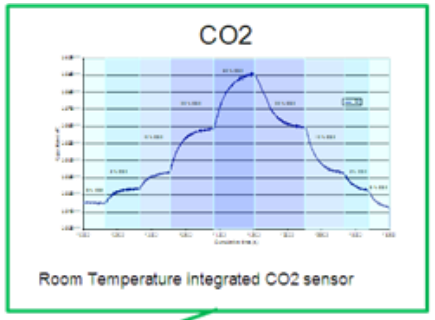


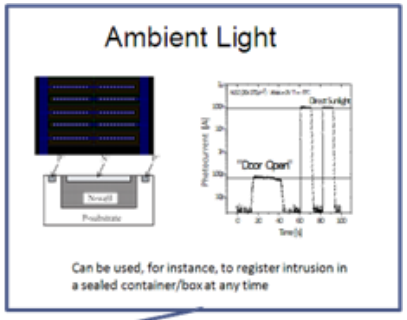
First CMOS integrated sensors prototype demonstration:
- Wireless read-out
- Single chip with Temperature, Relative Humidity and Ambient Light sensors

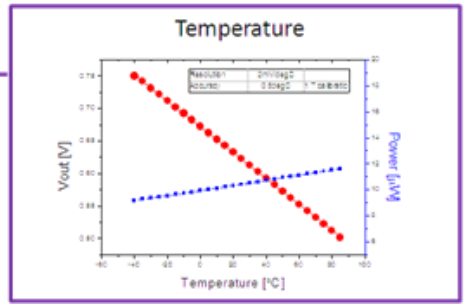
NXP Research Prototype (KOALA)

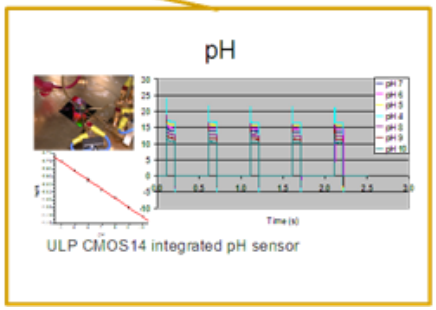


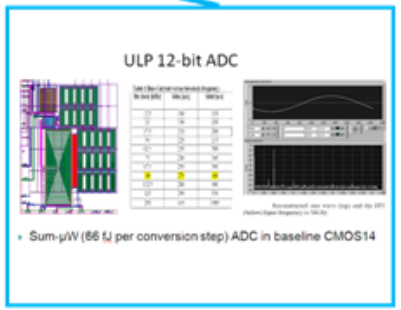










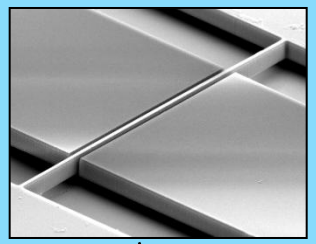


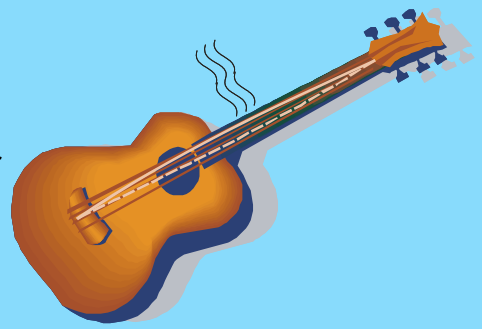
- CMOS integrated sensors test-chip
- “Add-on to baseline CMOS”: Gas phase (humidity, CO2, O2, C2H4), Liquid (Immersion, pH), Mechanical Shock, Pressure and Ambient Light sensors

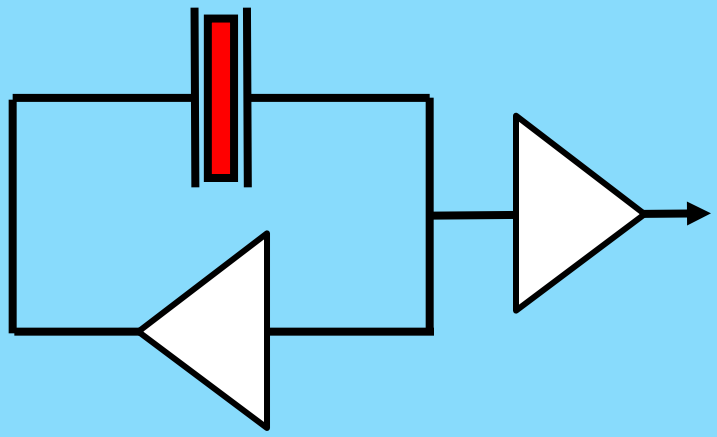
MEMS Timing Devices

MEMS based oscillator

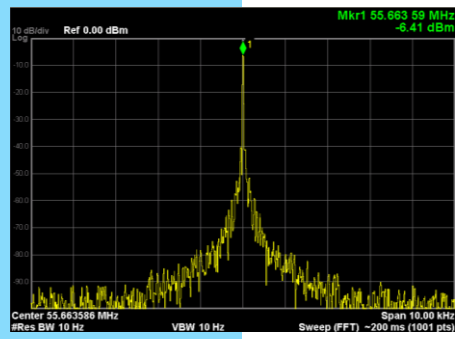
MEMS resonator



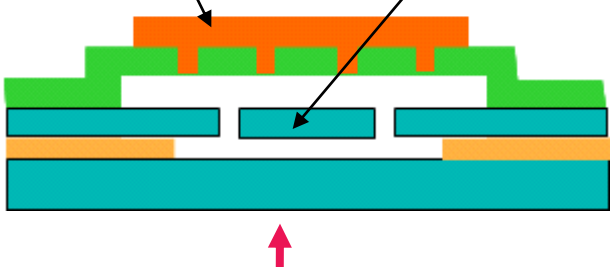




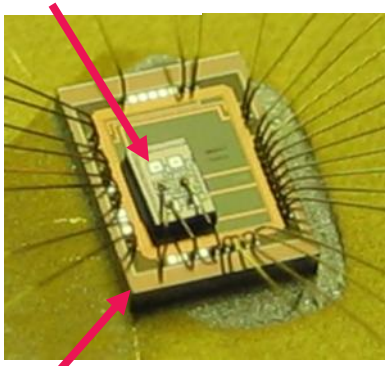
CMOS amplifier



accurate clock signal



On-wafer vacuum sealed MEMS resonator

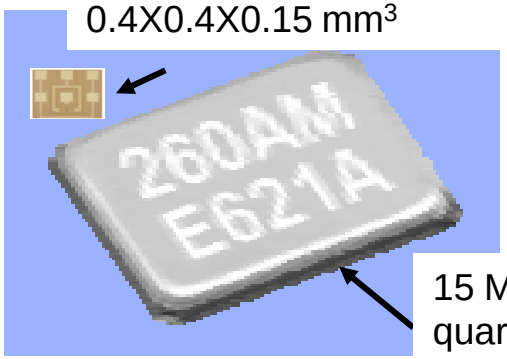


CMOS14 amplifier

A MEMS resonator is small, cheap, and Si

Small

15 MHz MEMS resonator
0.4X0.4X0.15 mm^3

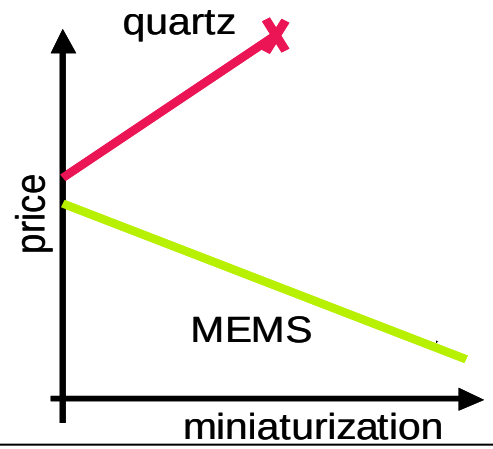


15 MHz
quartz resonator
2.5X2.0X0.55 mm^3

Inexpensive

- Processed 200 mm wafer contains ~ 100,000 devices
- Standard back-end processing (plastic molded packaging)

Scalable



Allows integration

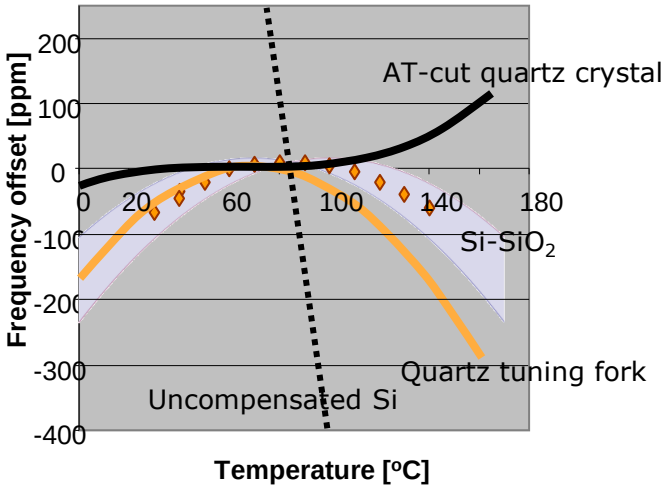
CMOS

quartz

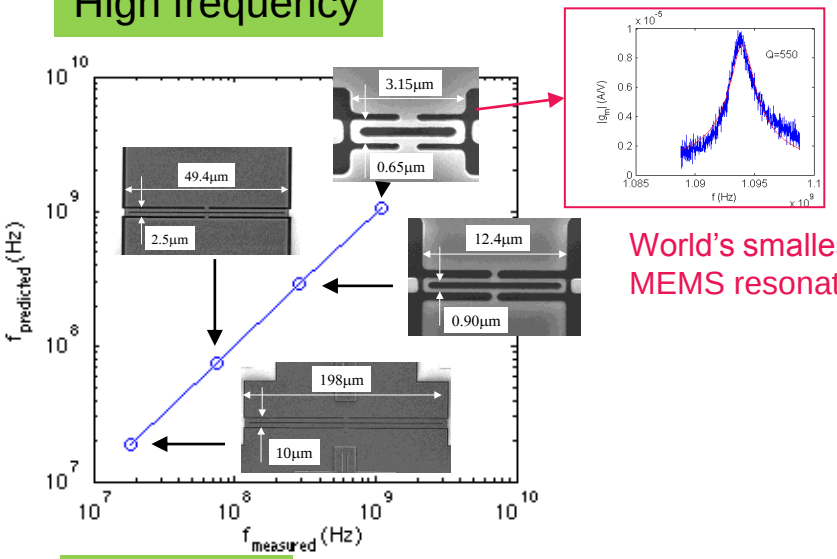
Less components

MEMS Timing Device technology

Low temperature drift

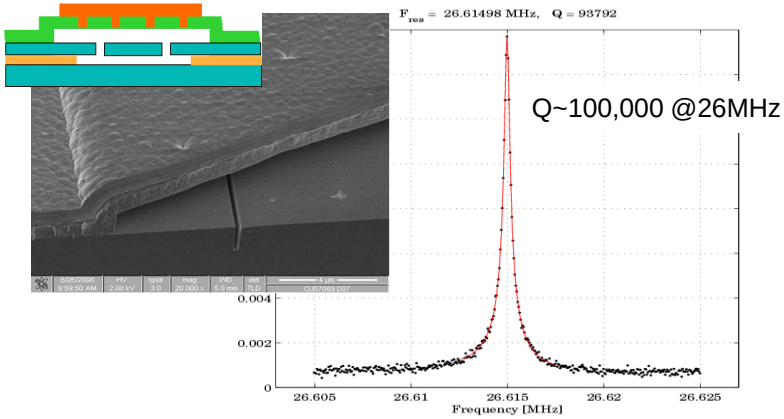


High frequency

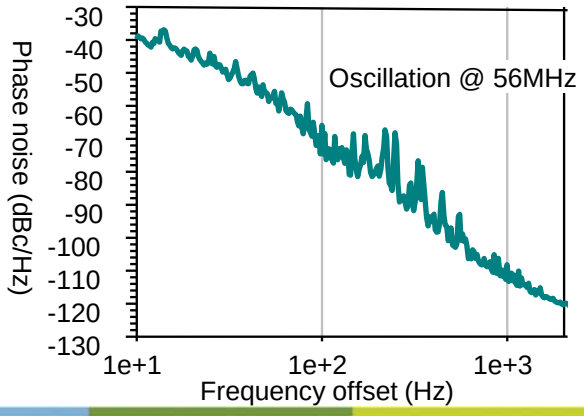


World's smallest MEMS resonator!!

On-wafer package



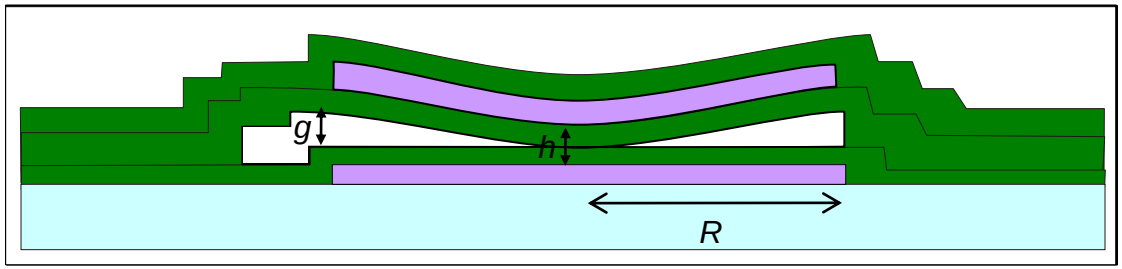
Low noise



Capacitive pressure sensor

- Capacitive pressure sensor
  - A (static) pressure causes a deflection of the membrane and thus a change in the capacitance.
  - For a circular membrane with electrode radius *R* and gap height *g* and electrode isolation thickness h_{diel} and deflection profile *w(r,P)*

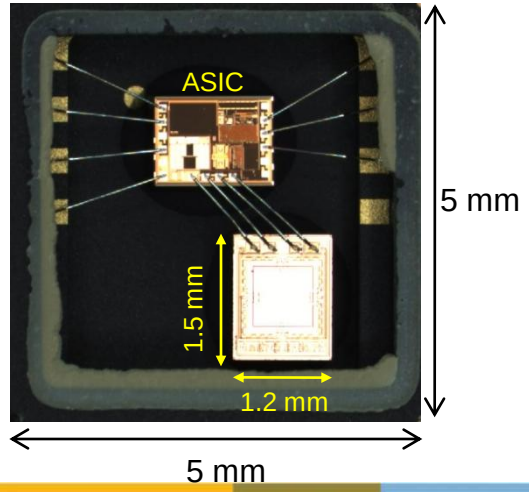
$$C = \frac{\varepsilon_0 A}{g} \quad \Rightarrow \quad C(P) = \int_0^R \frac{\varepsilon_0 2\pi r dr}{(h_{\text{diel}}/\varepsilon_{\text{r}}) + g - w(r,P)}$$



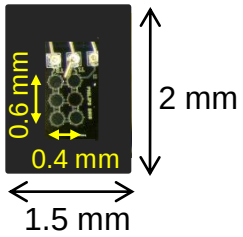
Advantages of capacitive sensor on CMOS

- Capacitive pressure sensor
  - low-power operation
- Pressure sensor integrated on CMOS
  - Low parasitic coupling: increased S-N
  - Reduced size & thickness for same sensitivity (>6x)
  - Single-die advantage

Piezoresistive read-out: dual die

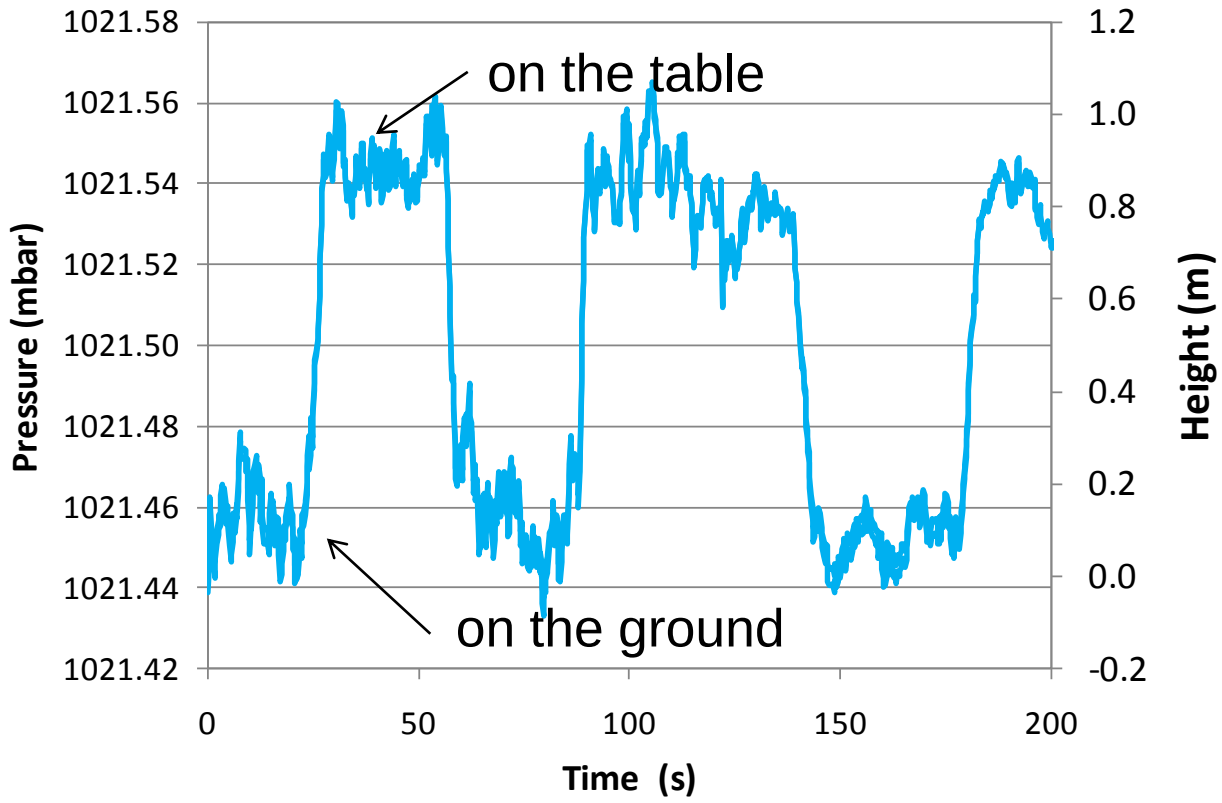


Capacitive read-out: single die

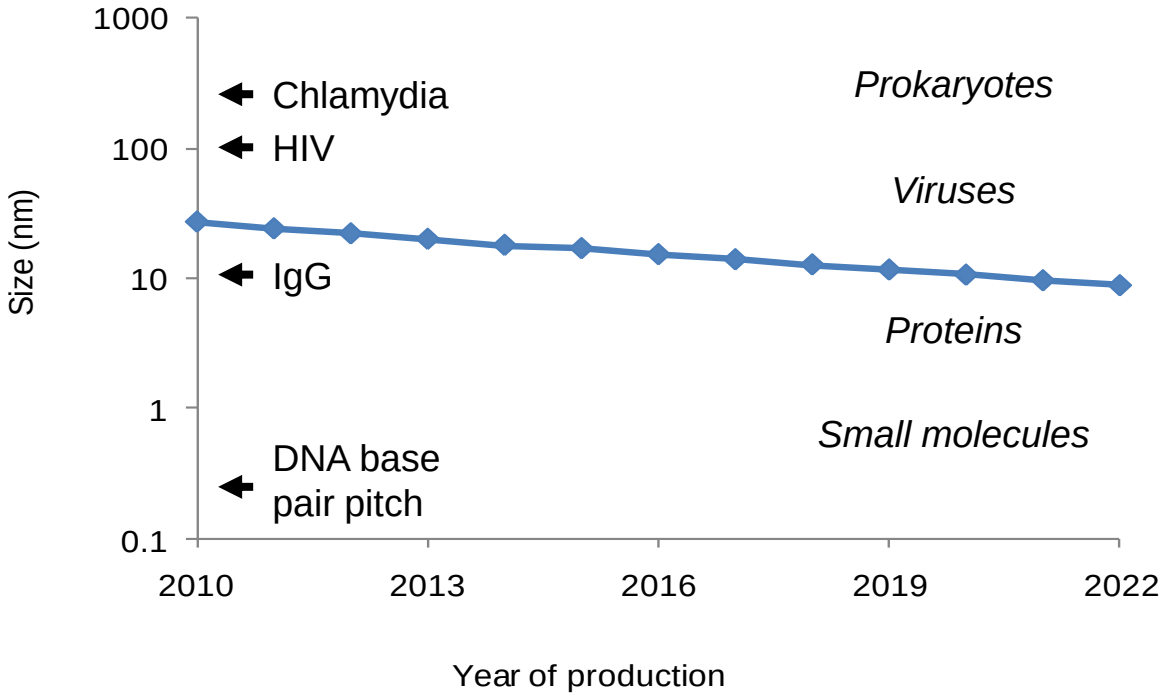


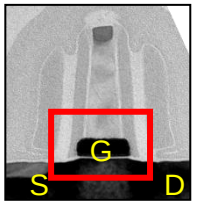
Pressure sensor performance

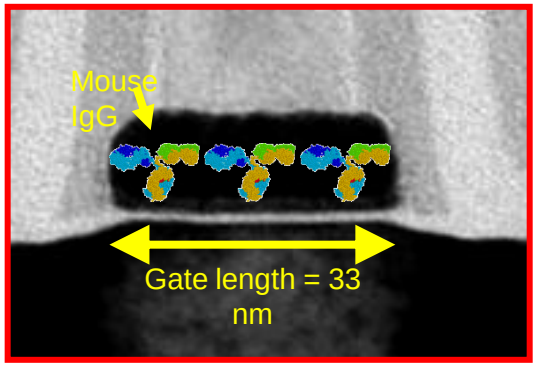
- Pressure resolution is better than 0.02 mbar (i.e. 2 Pa or 16 cm !!!) due to the 19 bit resolution of the capacitance to digital converter



CMOS scaling in relation to bio-sensing



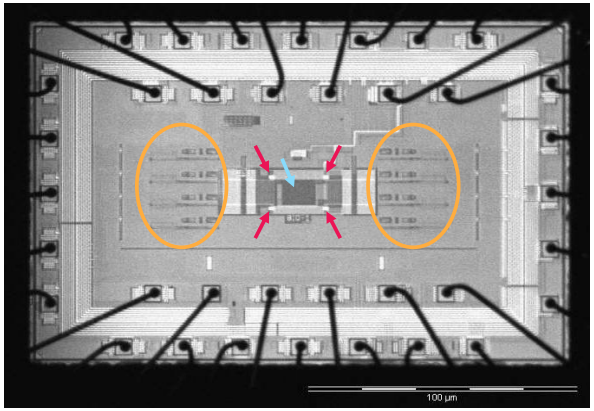




(ITRS 2009)

NXP Biosensor technology

- ***Standard C90 nm CMOS chip design***
  - Individual addressable electrodes
  - On-chip data storage
  - On-chip calibration

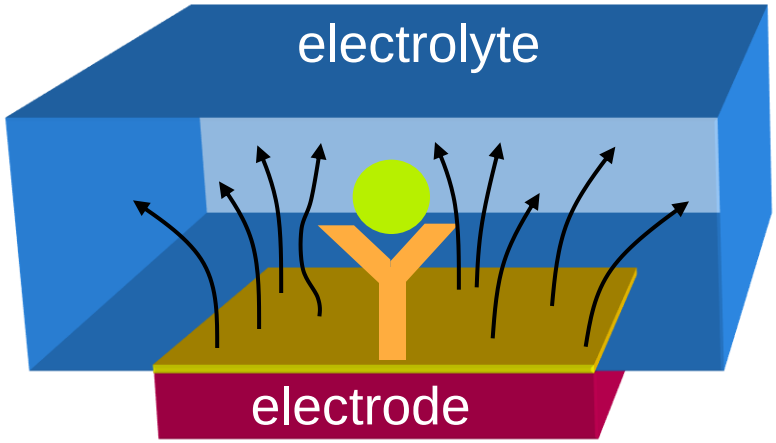


256 x 256 nano-electrodes

8 A/D converters

4 temperature sensors

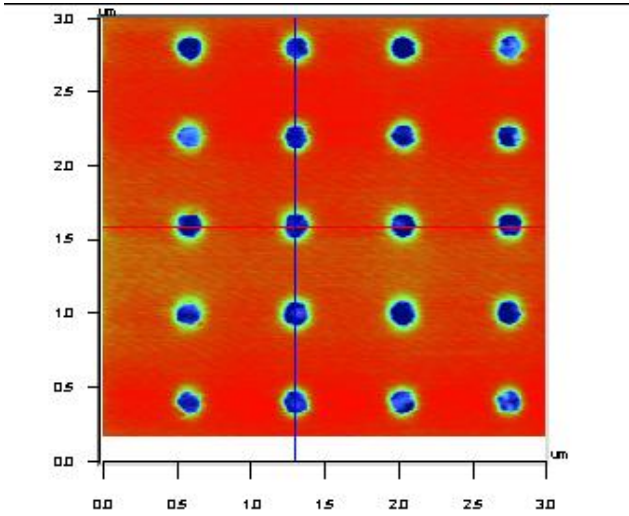
- ***Label-free capacitive detection on 180 nm nano-electrodes***



Sensor configuration

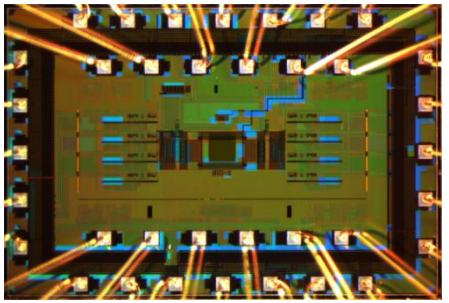
$$C = \varepsilon_{eff} \cdot \frac{A}{d}$$

Sensor principle



AFM picture nano-electrodes

Bio-sensor unique selling points

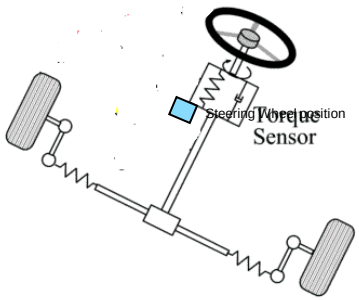


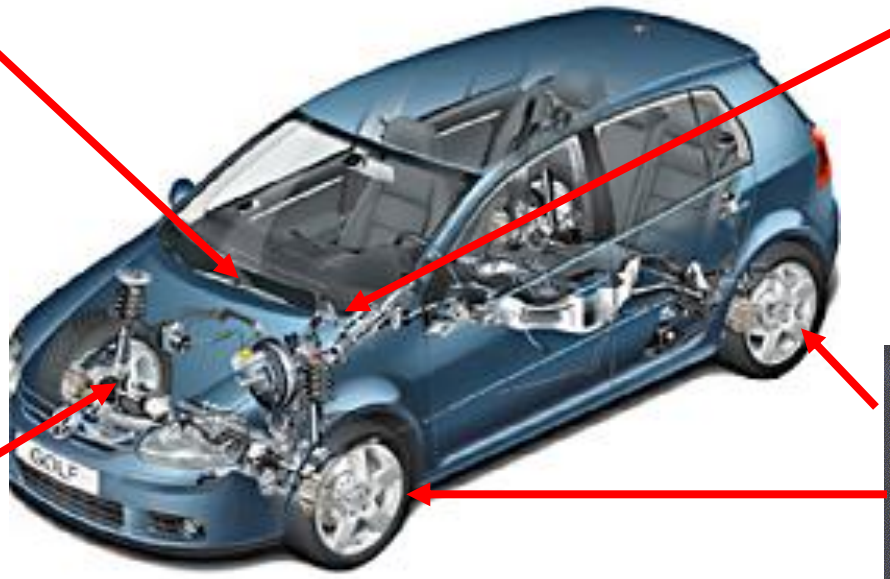
- Label-free detection platform applicable for affinity sensing: DNA/proteins
- Ability for multiplexing
- Very good time resolution: 0.2 s→ allows kinetic measurements
- Potential to measure in pM range
- Based on standard CMOS chip manufacturing → cost-effective

AMR sensor applications

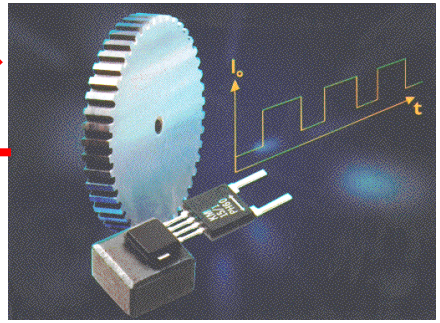
Window wiper
using
2 angle sensors KMZ43T

Adaptive steering
Using
3 angle sensors KMZ41





Throttle control
using
2 angle sensors KMA199E



ABS
using
4 wheel speed sensors KMI15

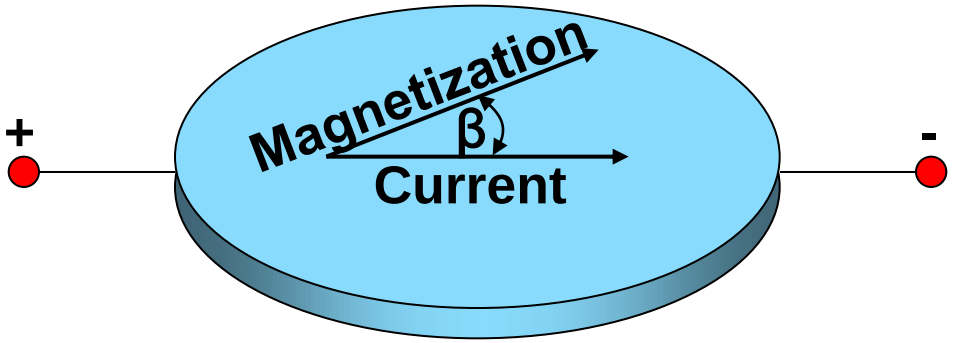
The AMR Effect

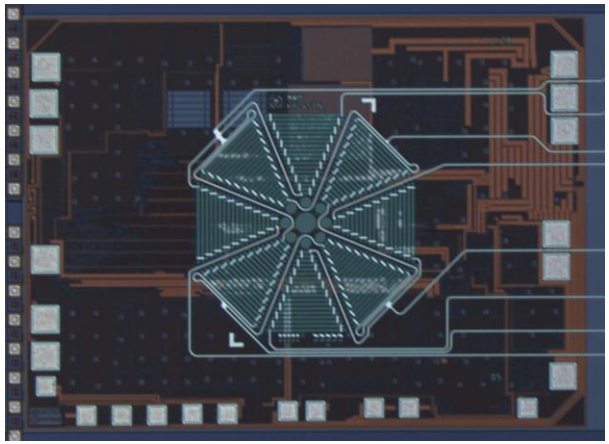
Relation b/w Resistivity and Direction of Magnetisation

- Due to the AMR effect in so-called transition metals (TMs) (e.g. Fe, Co and Ni) the electrical resistivity depends on *the angle between current and magnetization direction*

$\beta = 0° \Rightarrow R_{\parallel} = R_0 + \Delta R = R_{max}$

$\beta = 90° \Rightarrow R_{\perp} = R_0 = R_{min}$





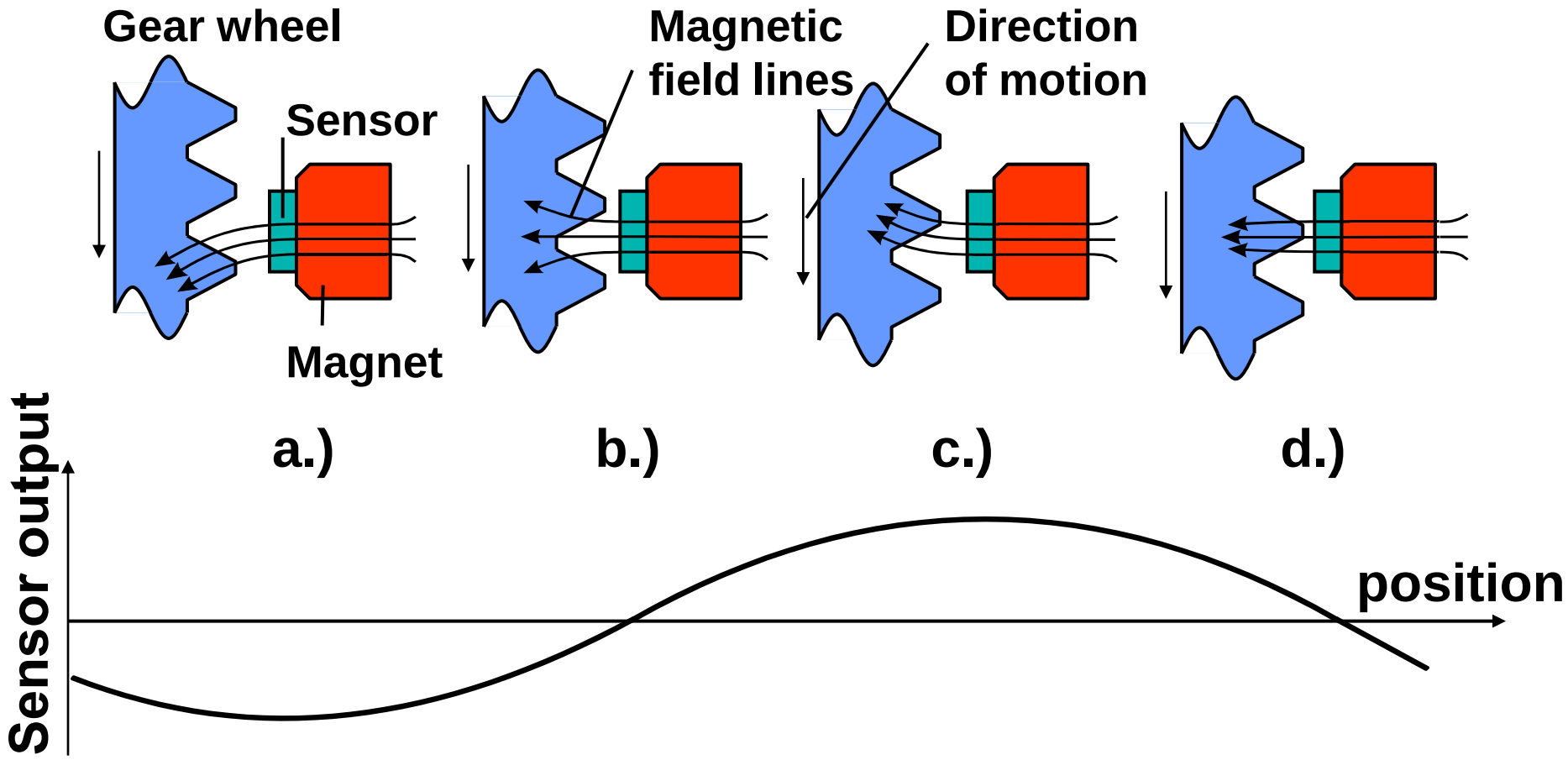
$R = R_0 + \Delta R \cdot \cos^2\beta$

Typical MR ratio for NiFe 81:19 → 2,2%

MR ratio

$(R_{\parallel} - R_{\perp})/ R_{\perp} = \Delta R/ R_{\perp}$

Principle of AMR based Rotational Speed Measurement



Key messages

- Sensors & Actuators are natural fit to NXP's HPMS strategy
- Go with the (CMOS process) flow:
  - Mainstream CMOS forms a baseline for many of our process developments
- Trend towards co-integration of Sensors & Actuators on CMOS
  - Several sensors on a single die: parallel processing & correlation possible
  - CMOS circuitry close to sensor : low parasitics, improved power efficiency
- Sensors & Actuator development requires holistic approach:
  - Co-design of driver/reader electronics together with sensor/actuator

Acknowledgement

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