NORDIC SEMICONDUCTOR

ASIC for MEMS

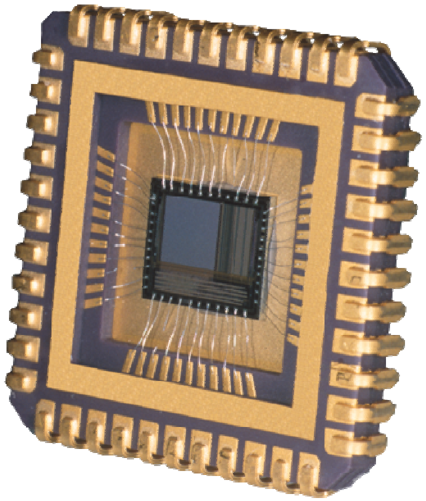
UiO

3 November, 2005

ASIC for MEMS

Agenda 3/11-05:

- **Introduction**
- **Sensor-ASIC**
- **(Some) Practical Aspects of ASIC-Design**
- **Wrap-up**



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Introduction

Who am I?

- John Raaum. M.Sc. NTH 1991.
- 2 years at the Norwegian Defense Research Establishment (FFI)
- At Nordic Semiconductor since '94.
- At SensoNor '98.
- Senior Technical Manager
- Personal experience from the following sensor-applications:
  - On-chip temperature sensor
  - On-chip voltage monitor
  - Low-Power Piezo-resistive sensor for Tire-Pressure
  - Resonating sensor for airbag application
  - Piezo-resistive sensor for airbag application
  - Optical-loop for keyless entry
  - Capacitive interface for roll-over sensor (angular rate sensor)
  - Ultrasonic flow-meter

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NORDIC SEMICONDUCTOR IS

A 20 year old Fabless Semiconductor Company

Producer of standard ”off-the-shelf” RF components

Turn-key developer and supplier of custom components

Intellectual Property (IP) supplier with advanced A/D, D/A and RF modules

Worldwide company with representatives on all continents

A leading Norwegian Technology Company listed on the Norwegian Stock Exchange

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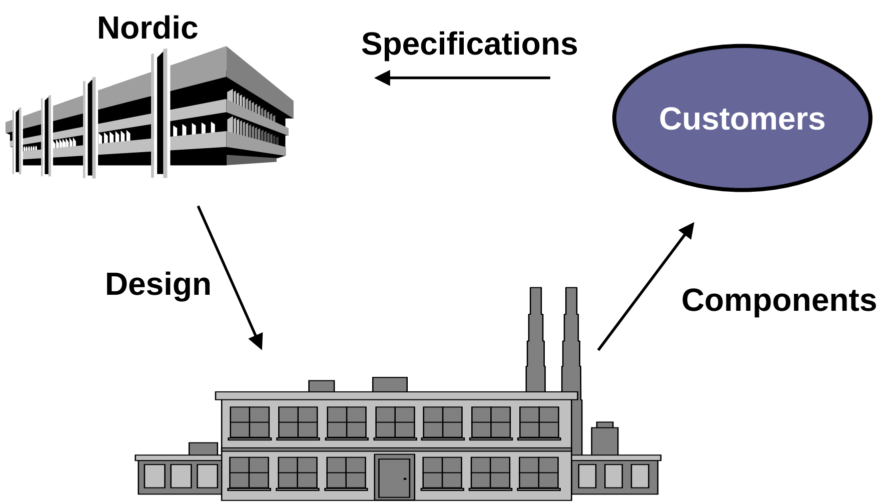
SOC SUPPLY CUSTOMER WITH COST-EFFECTIVE COMPONENTS

Before: Tightly integrated value chain

Design → Industrial-ization → Wafer → Packaging Testing → Sales/ Logistics

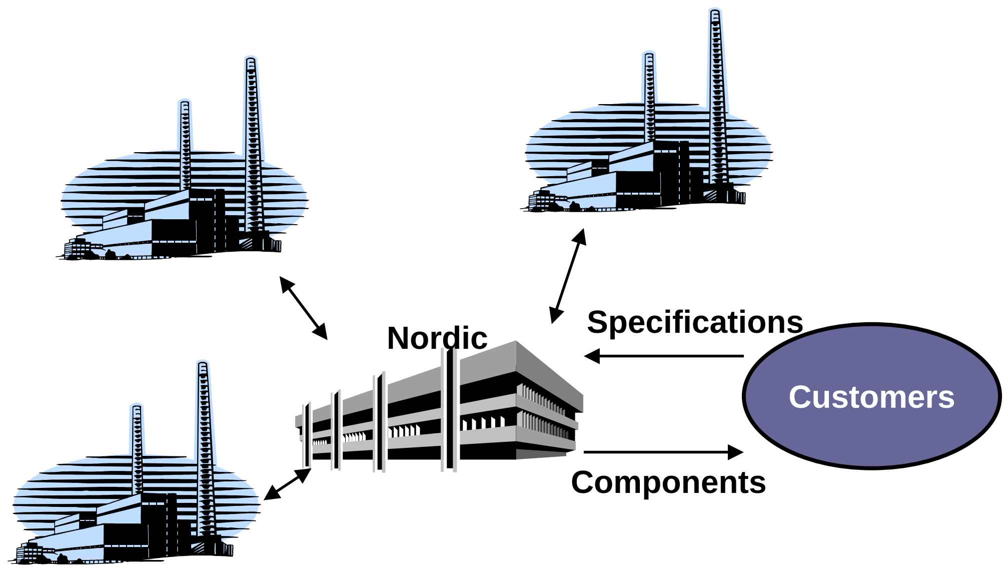
Semiconductor business dominated by highly integrated companies such as Phillips, Motorola and Texas Instruments



Today: Disintegrated value chain

Design → Industrial-ization → Wafer → Packaging Testing → Sales/ Logistics

Economies of scale and huge capital investments has created highly specialised companies that together are most cost-effective than integrated companies



Nordic, the system integrator in the driver's seat

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NORDIC IS A TURN KEY DEVELOPER OF CUSTOM SOLUTIONS

Custom Analog, Digital or Mixed Signal Design	System-on-Chip Design and Platform IP	Netlist Hand-Off and Back-End Services	Component Manufacturing
"CustomExpress" "RFExpress"	**"SoCExpress"**	**"PhysicalExpress"**	**"Manufacturing"**

"CustomExpress" "RFExpress"

Custom design services
- Advanced Analog
- Complex Digital
- Mixed Signal
- Sensor Design
- RTL Synthesis
- Proven RF-IP

"SoCExpress"

SoC Development
- 8051 Based platforms
- Analog Modules
- Simulation Support

"PhysicalExpress"

Back-End Services
- Automatic Layout
- Layout verification
- Test program (ATPG)
- DRC/ERC
- LVS
- GDS-II Generation

"Manufacturing"

Manufacturing
- Mask Production
- Wafer Production
- Wafer test
- Assembly/packaging
- IC test
- Prototypes
- Volume production

State-of-the art tools and subcontractors throughout process

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Sensor-ASICs

The mission:

Signal conditioning, temperature compensation and data formatting of raw data from various types of sensors

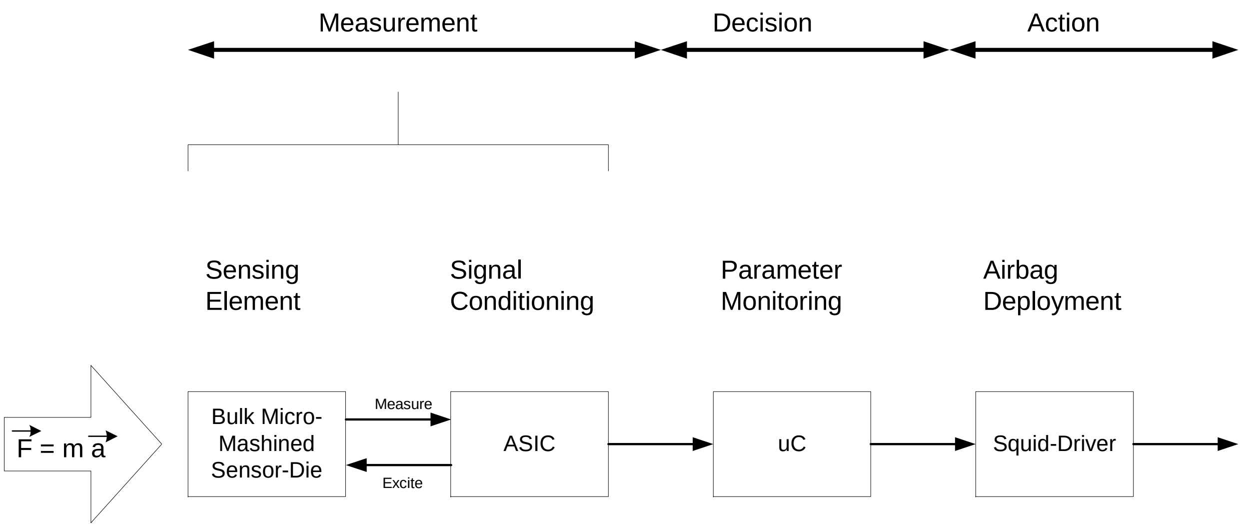
Why?

Improved linearity, noise, accuracy, …

How?

Custom sensor-ASICs from Nordic Semiconductor

The operational chain



Key Issue:

Conversion of physical parameters to electrical signals in a mechanical setting!

Sensor-ASICs

Typical spec of sensing element:

- **Sensitivity with large tolerance: +/-30%**
- **High temperature drift of sensitivity: +/-15%**
- **Large zero-point error: +/-Full Scale Output (FSO)**
- **Large noise bandwidth: Mechanical filter with resonances**
- **Analog output (Whetstone measurement bridge)**
- **Capacitive / resonating element - need for excitation**
- **Built-in self-test facility**

Sensor-ASICs

Typical spec of sensor product (Automotive example):

- **Sensitivity with tight tolerance: +/-3%.**
- **Low temperature drift of sensitivity: +/-1.5%.**
- **Small zero-point error: +/-1% of FSO.**
- **Well controlled noise bandwidth.**
- **Minimised group delay.**
- **Any output format: Analog, PWM, SPI, parallel digital, current loop, ...**

Even better accuracy for high end sensors.

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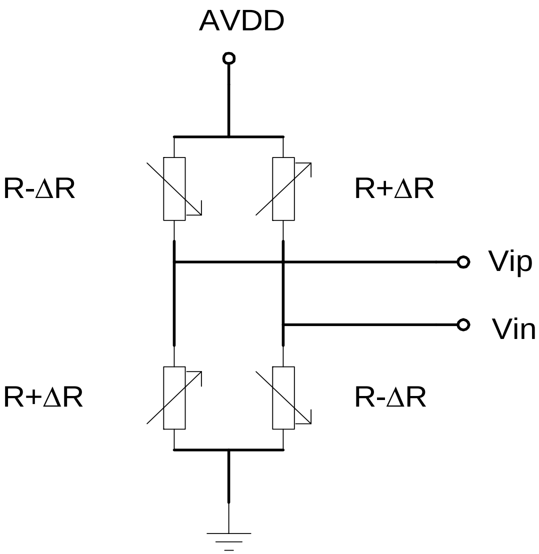
Resistive measurement bridge



Signal:

$$Vip = AVDD \cdot \frac{R+\Delta R}{2R}$$

$$Vin = AVDD \cdot \frac{R-\Delta R}{2R}$$

$$Vin_{diff} = Vip - Vin = AVDD \cdot \frac{\Delta R}{R}$$

$$Sensitivity: \Delta R(p) = \Delta R \cdot p$$

$$R-Mismatch: \Delta R(p) = \Delta R_{zero} + \Delta R \cdot p$$

$$Supply-noise: AVDD + n_{AVDD}$$

$$Vin_{diff}(p) = Vip - Vin = (AVDD + n_{AVDD}) \cdot \frac{\Delta R(p)}{R} = AVDD \cdot \frac{\Delta R_{zero}}{R} + n_{AVDD} \cdot \frac{\Delta R_{zero}}{R} + AVDD \cdot \frac{\Delta R}{R} \cdot p + n_{AVDD} \cdot \frac{\Delta R}{R} \cdot p$$

$$Vin_{diff}(p) \approx V_{ofs} + noise + AVDD \cdot S_p \cdot p$$

=> Ratiometric output with sensitivity S_p

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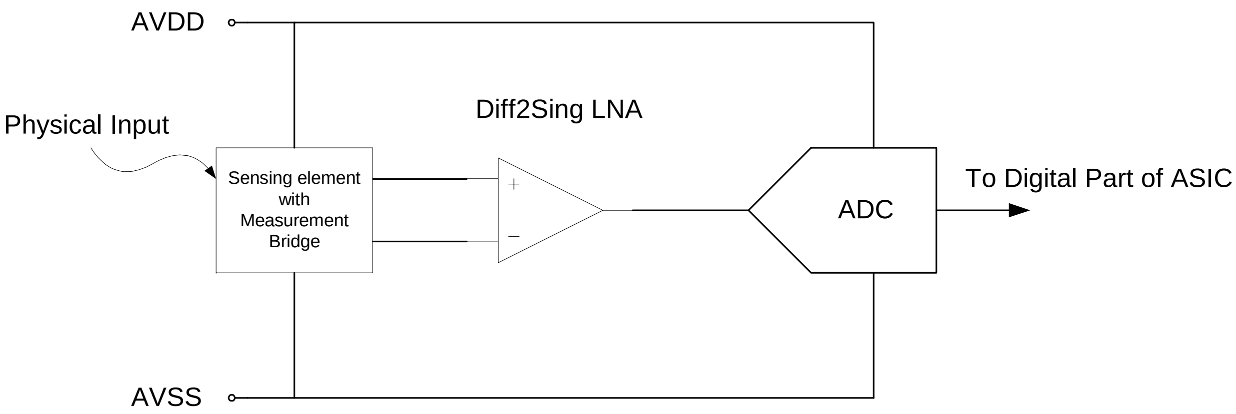
Sensor / ASIC front-end



Ratio-metric cancellation:

- **AVDD-dependent input signal**
- **AVDD-dependent ADC reference voltages**

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Accuracy Management

Purpose of Signal Conditioning in ASIC:

Reduce overall tolerance over PVT from +/-50-150% to +/-1-5%!

Typical Overall Transfer Function:

$$V_{out}(p, AVDD, T, P) = AVDD \cdot S_p(T, P) \cdot p \cdot G_0(P) \cdot S(T, P)$$

S(T,P) is typically a programmable N-order polynomal implementing the inverse temperature drift of S_p(T,P).

G_0(P) is a programmable gain adjusting the sensitivity at room temperature.

High pass filters remove unintentional zero voltage (offset voltage).

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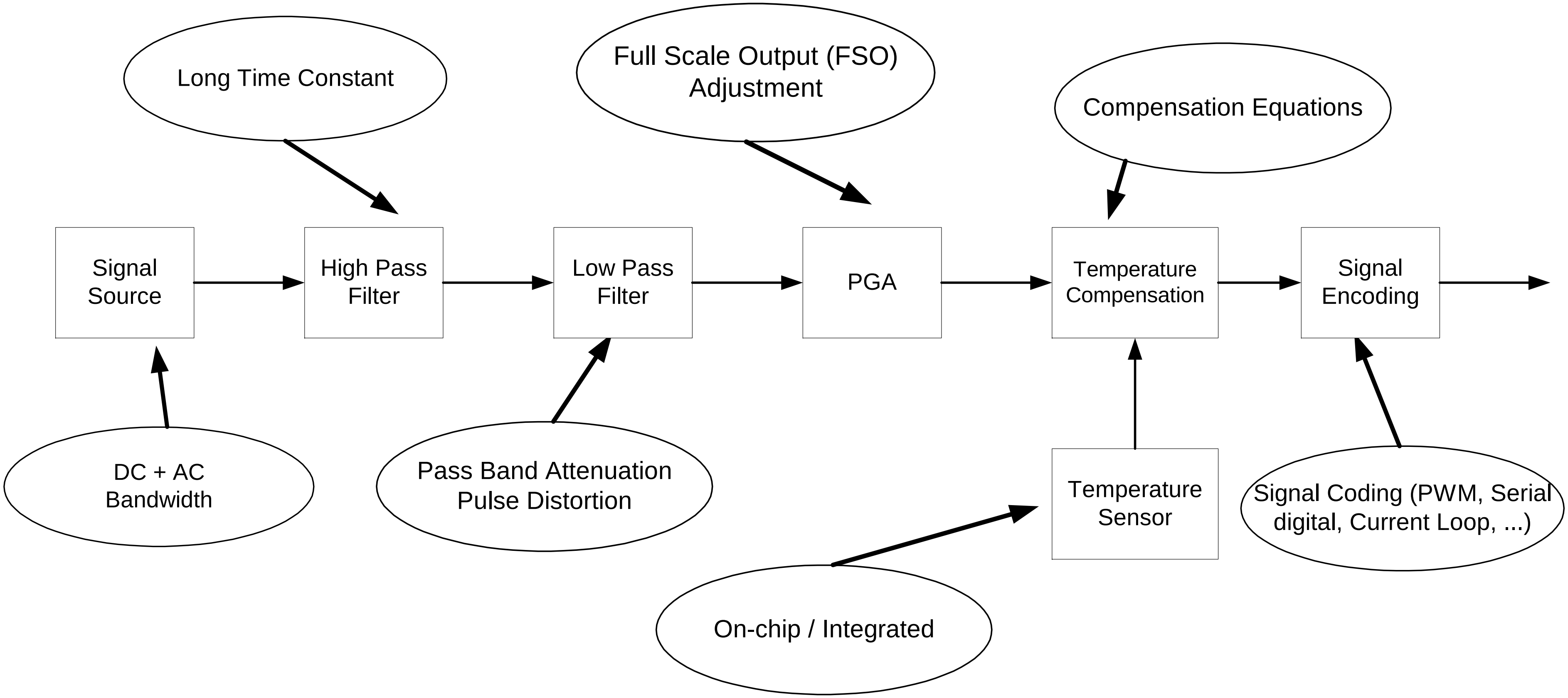
Typical Signal Conditioning



When you know your signal chain

- Do you know you input signal??

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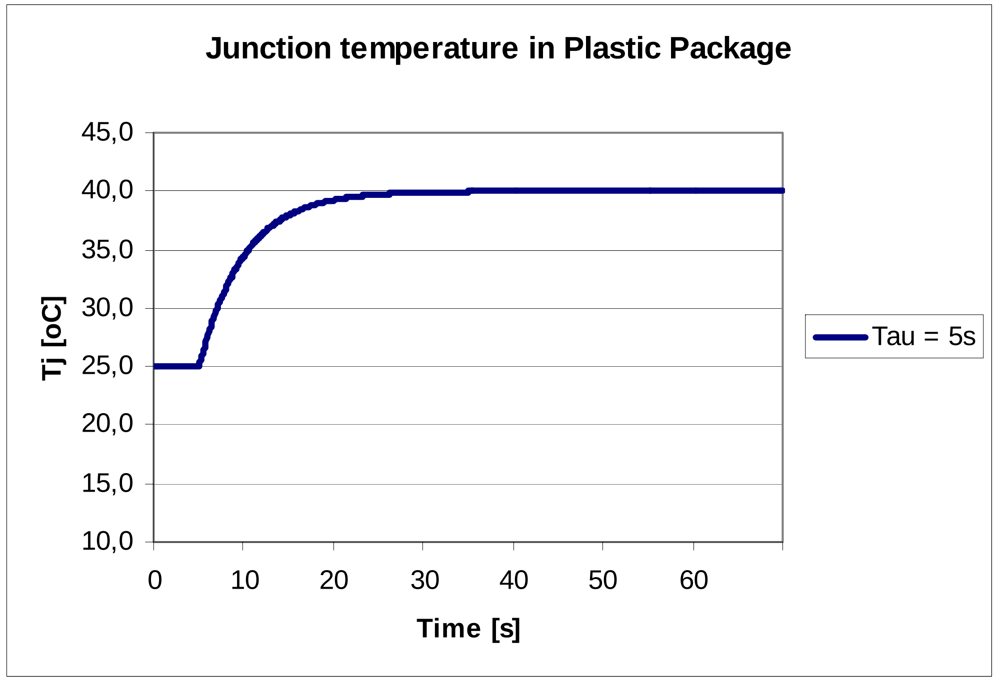
Thermal Aspects

Standard Model:

Dynamic Model:



$$T_j = T_{amb} + P \cdot \theta_T \cdot (1 - e^{-\frac{t}{\tau}})$$

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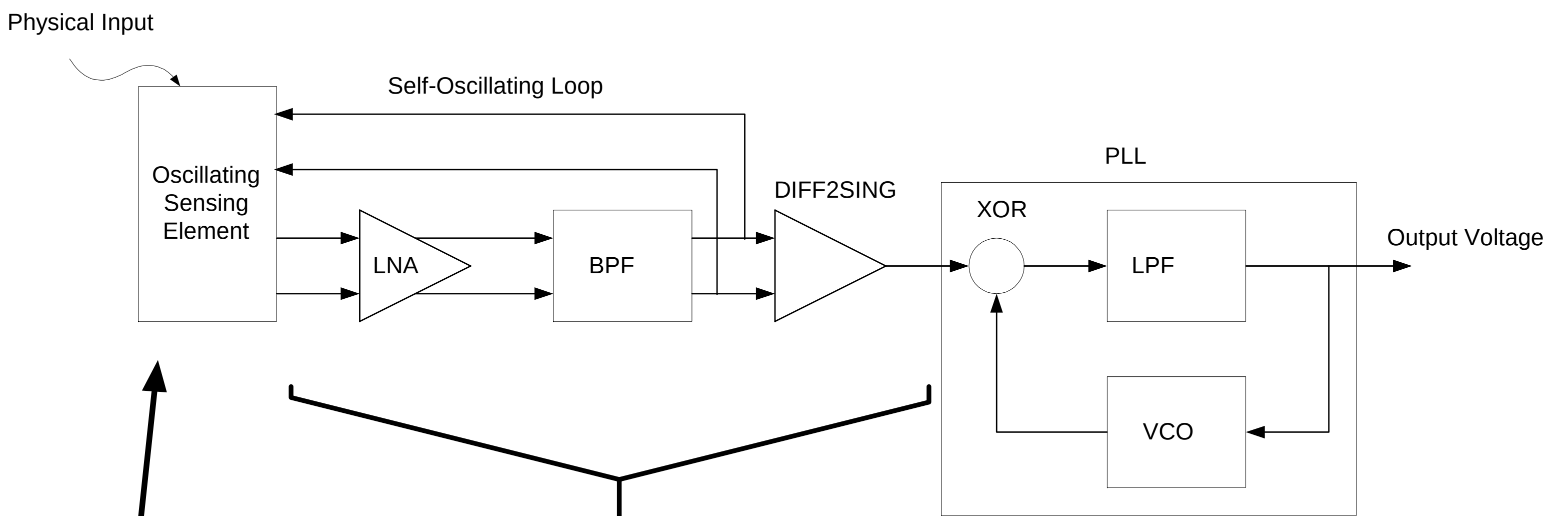
Case: Frequency Modulating Sensor

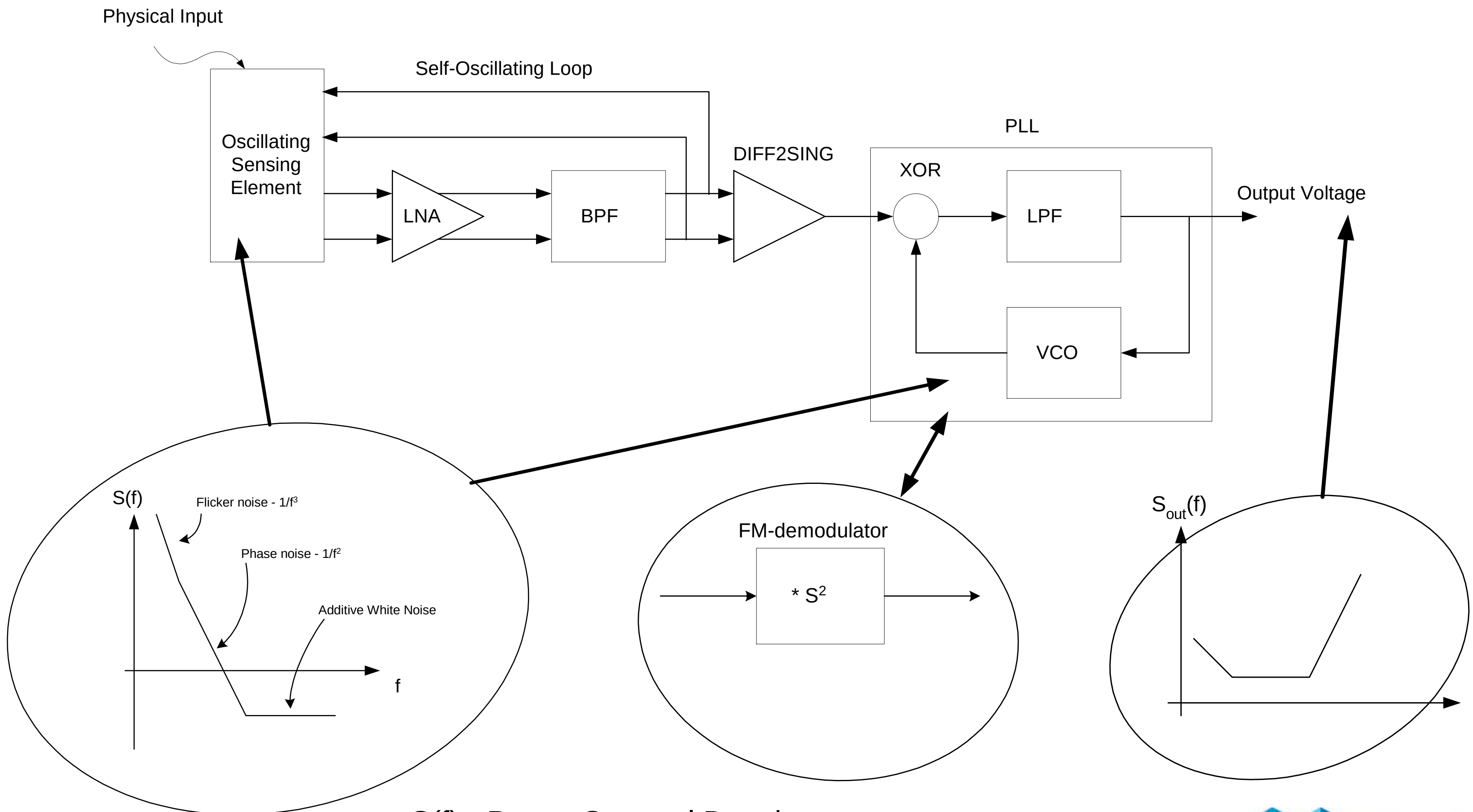


Output Frequency Dependent On Physical Input Parameter (Frequency Modulation)

FM front-end for SNR optimisation / spurious removal

FM-demodulator - Internal VCO follows input FM-carrier => decoding of physical input parameter (controlling parameter)

Case: Frequency Modulating Sensor



S(f) - Power Spectral Density

Tools and Methology

Essential for Design of Sensor-ASICs:

- **Simulation Model of Sensing Element**
- **System and Signals Know-How**

Make Your Spec Executable:

- **Matlab/Simulink**
- **HDL-modelling**
- **ADMS**
- **SPICE**
- **Careful Budgeting (Monte Carlo Analysis)**

Sensor-ASICs

What to look for in Sensor- / ASIC-spec?

- **ppm accuracy (including noise)**
- **Very low frequency filters**
- **Low power at elevated temperatures**
- **Start-up time**
- **Testability**
- **...**

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Define Your Design Environment

Specification with Parameter Budgeting

Power-strategy

ESD-strategy

Bias-strategy

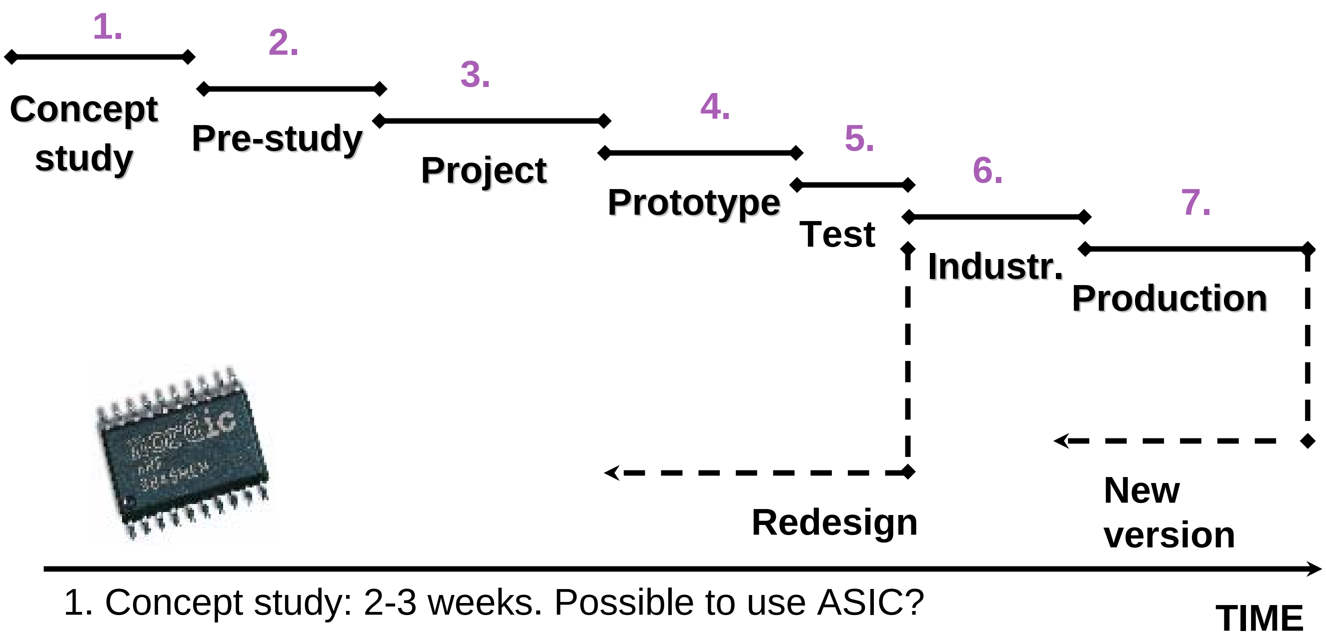
Test-strategy

Floorplan (Area-estimates with Seal and Scribe)

Analog vs Digital - Optimize cost vs performance

Process Options - Optimize cost vs performance

Workflow ASIC project



1. Concept study: 2-3 weeks. Possible to use ASIC?

2. Pre-study: 3-6 weeks. Specification of ASIC.

3. Project: 3-6 months ASIC development (depending on project complexity)

4. Prototype production: 6-12 weeks. Implementation of production test..

5. Test at customer site: 4 weeks. Prototype test in customers application.

6. Industrialisation: 8-12 weeks. Qualification and transfer to production.

7. Production: Lot acceptance and yield monitoring..

Reliability #1/2

All stages in the product development includes *product reliability* tasks.

The overall target is to create a robust, high quality product, meeting the specification and resistant to expected external stress.

The target of the product qualification is to prove that the product is resistant to expected external stress.

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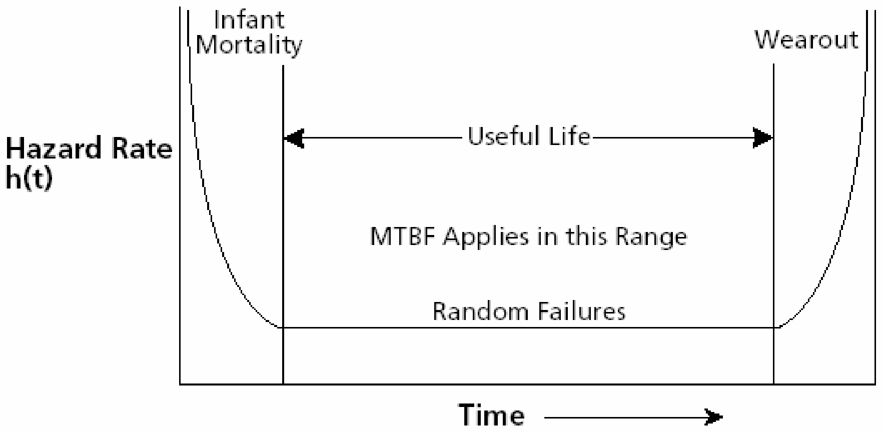
Reliability #2/2

- Lifetime testing evaluate useful life
- Burn in removes Infants
- FIT-calculations determine MTTF



MTTF [Years]

FIT	NUMBER OF PARTS PER SYSTEM									
	1	2	4	8	16	32	64	128	256	512
1	114155.25	57077.63	28538.81	14269.41	7134.70	3567.35	1783.68	891.84	445.92	222.96
10	11415.53	5707.76	2853.88	1426.94	713.47	356.74	178.37	89.18	44.59	22.30
100	1141.55	570.78	285.39	142.69	71.35	35.67	17.84	8.92	4.46	2.23
1,000	114.16	57.08	28.54	14.27	7.13	3.57	1.78	0.89	0.45	0.22
10,000	11.42	5.71	2.85	1.43	0.71	0.36	0.18	0.09	0.04	0.02

Figures from Micron TN-00-14

Wrap-up

What should be remembered?

- **Caution: Signal Conversion in Mechanical System**
- **Caution: Be Aware of Input Signal Spectrum**
- **Caution: Be Aware of Side-Effects of Important Functional Modules (Thermal effects ...)**
- **Caution: Unable to Make Simulation Model of Your Sensor => Unable to Design Signal Conditioning?**
- **Caution: Always Utilise Best Practice Mixed-Signal Design Methology**
- **Caution: Don’t forget cost optimisation, production test and reliability!**

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