3rd LEIBNIZ CONFERENCE OF ADVANCED SCIENCE

Neue Konzepte für Bauteil- und Materialüberwachung in der Verkehrstechnik, speziell Bahn und Flugzeug

Norbert Meyendorf

Fraunhofer Institute for Non-Destructive Testing,
Dresden branch (IZFP-D)

Fraunhofer IZFP Institut Zerstörungsfreie Prüfverfahren

Neue Konzepte für Bauteil- und Materialüberwachung in der Verkehrstechnik, speziell Bahn und Flugzeug

Outline

- The dawn of a new technology age
- Progress in science and technology for SHM
- SHM - A new discipline in technology
- Attempt of a prognosis

Fraunhofer IZFP Institut Zerstörungsfreie Prüfverfahren

We are at the dawn of a new technology age

1. Century Heron of Alexandria

1700 Thomas Newcom

1769 James Watt

1792 Wing Telegraph

1833 Electromagnetic. Telegraph (Morse)

1901 Picture Telegraph

1909 Nobel Price for Wireless Teleg.

Simple Sensors

1960 Sensors +Amplifiers

2000 Complex Smart Sensor Systems

Sensor Networks

Age of industrialization

Mechanic Machines
replace human muscle power

Age of information

Electronic Machines
replace
human memory

Age of decision

Smart Systems
replace
human decisions

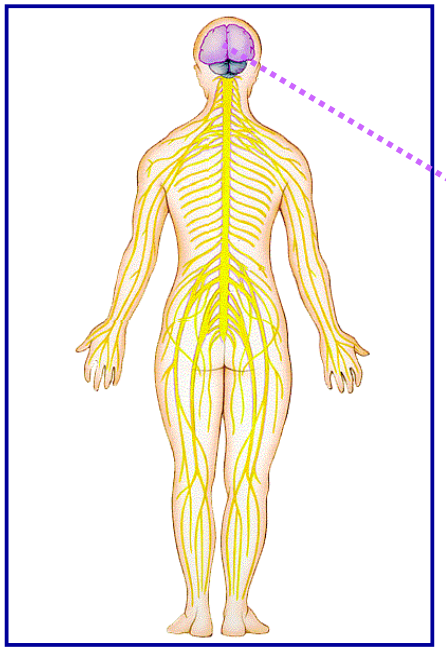
1700 1800 1900 2000

Fraunhofer IZFP Institut Zerstörungsfreie Prüfverfahren

Why SHM now?

The ultimate goal

Building smart systems that are sensitive to their environment and their “health” situation **and can adapt to this situation**.



***Human nervous system*: detection of intensity and location of pain and doctor visit judgement**

Evaluation

Courtesy Speckmann Airbus

***SHM system:* monitoring of airframe and evaluation of the follow up maintenance actions**

The dawn of a new technology age

Why SHM now?

The increasing memory power and processor speed allow making

systems small and light weight

Reducing energy consumption allows making

systems energy independent

Falling prices allow

multiplying of systems

Wireless communications allows establishing

affordable “intelligent” sensor networks

International networking of scientists allows using

most advanced technologies and resources.

IZFP
Fraunhofer Institut Zerstörungsfreie Prüfverfahren

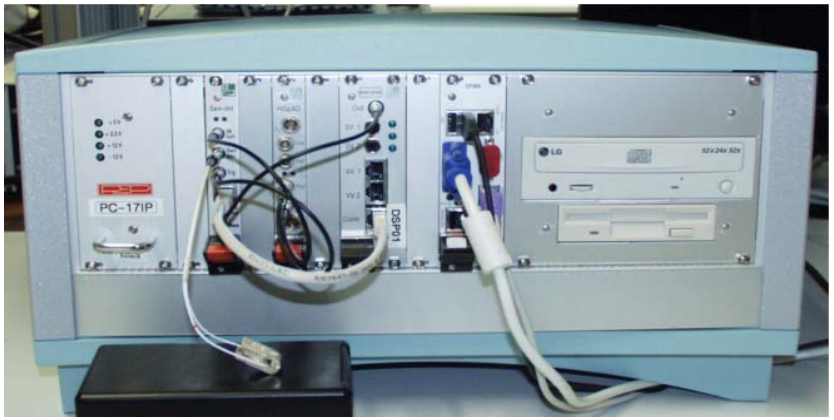
The dawn of a new technology age

Miniaturization of Electronics

Conventional acoustic data recording and analyzing system

➔ **4 Channel acoustic system today**

➔ **Match-X-Module**



CPCI system with modules for signal recording and analysis

Network nodes based on FR4 technology

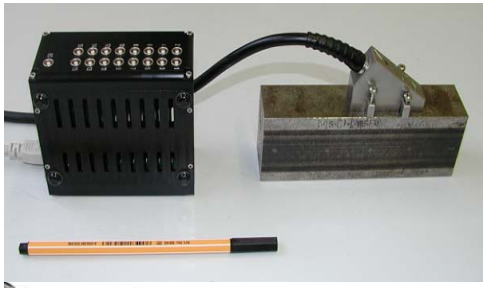
Network nodes based on Al_2O_3 technology

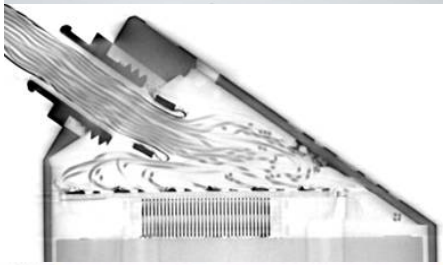
Fraunhofer IZFP Institut Zerstörungsfreie Prüfverfahren

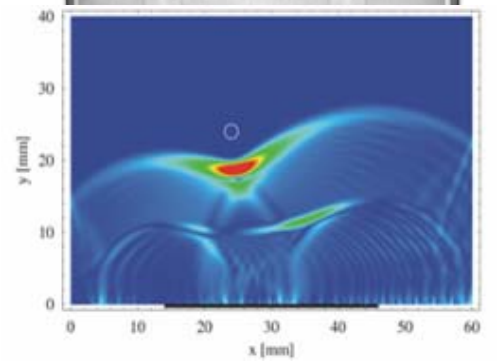
The dawn of a new technology age

Resources for Structural Health Monitoring: Nondestructive Evaluation

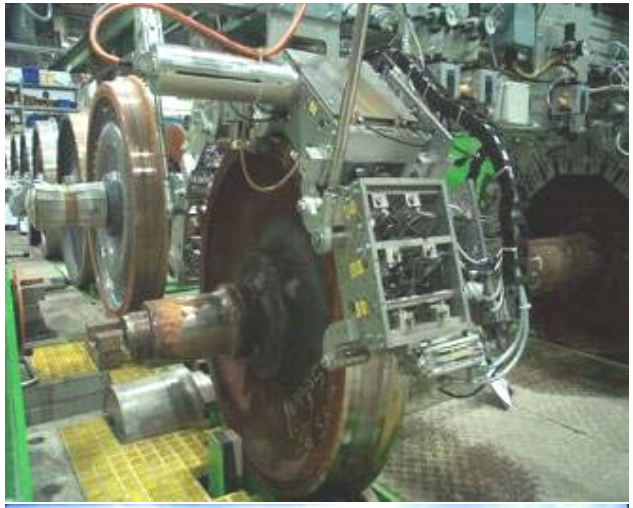
- *Single* Probe Technique -



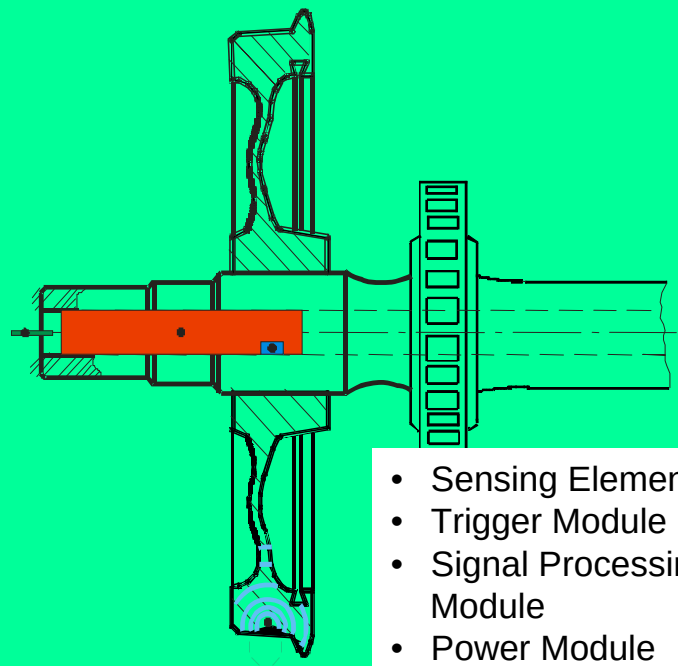




- *Multi* Probe Technique -



- *Local* Probe Technique -



- Sensing Element
- Trigger Module
- Signal Processing Module
- Power Module
- Telemetry Module

Fraunhofer IZFP Institut Zerstörungsfreie Prüfverfahren

Benefits of SHM

- Accelerated structure tests
- Reduced maintenance cycles
- Reduced maintenance time
- Higher availability of systems
- Condition based maintenance
- Increased safety and reliability
- Extended use of systems within lifetime
- Maintenance of systems retail value
- Extended lifetime (if in time repair)
- Optimized design (if SHM is incorporated in design rules)
- Reduced weight and lower energy consumption

Neue Konzepte für Bauteil- und Materialüberwachung in der Verkehrstechnik, speziell Bahn und Flugzeug

Outline

- The dawn of a new technology age
- Progress in science and technology for SHM
- SHM - A new discipline in technology
- Attempt of a prognosis

Fraunhofer IZFP Institut Zerstörungsfreie Prüfverfahren

Progress in science and technology for SHM

Advanced sensor and NDE principles

➔ Advanced electronics

Advanced data acquisition and processing techniques

Embedded sensors

Distributed sensor systems and sensor networks

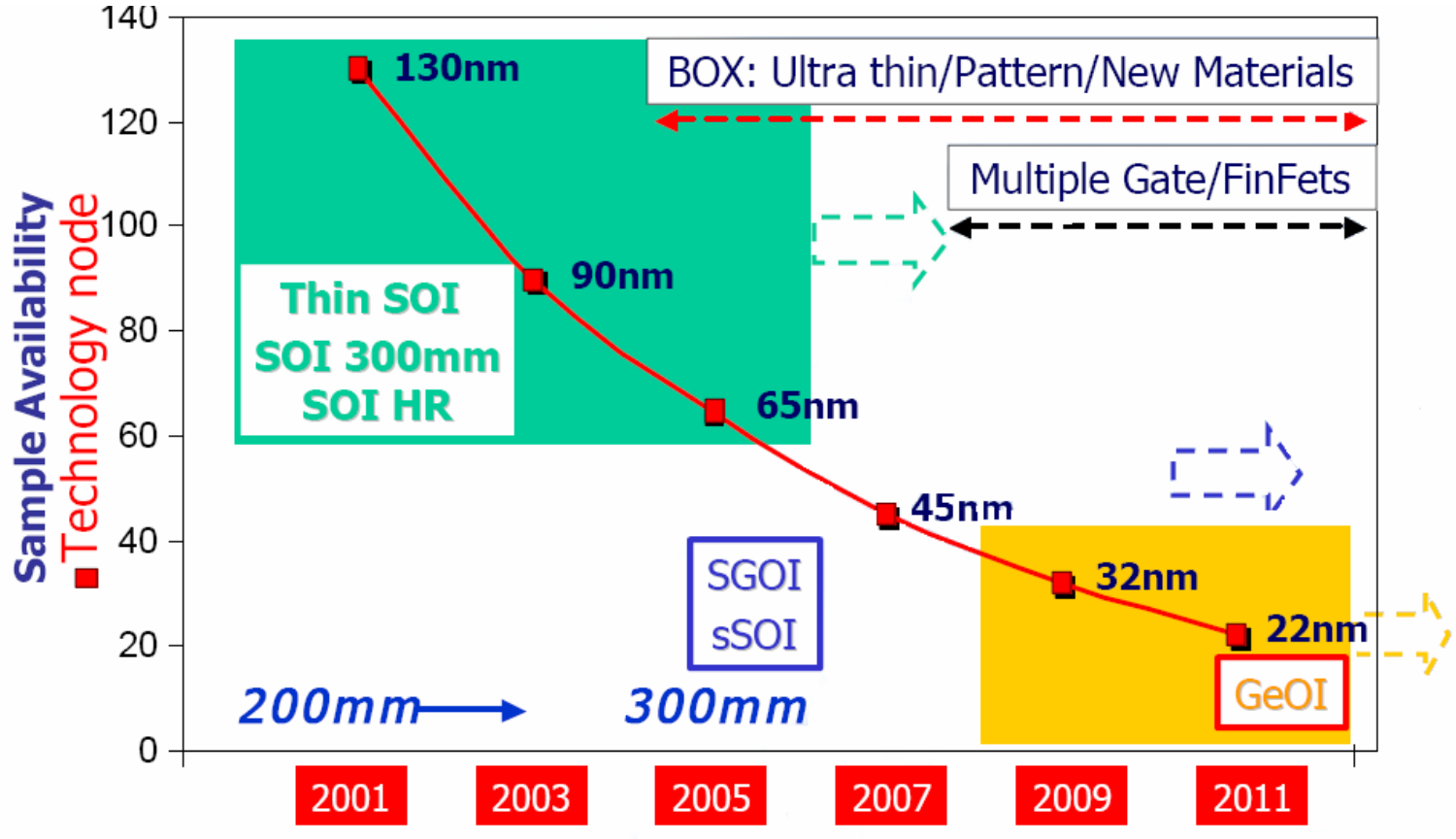
Telemetric systems

New concepts for power supply

Monitoring of complex structures

Fraunhofer IZFP Institut Zerstörungsfreie Prüfverfahren

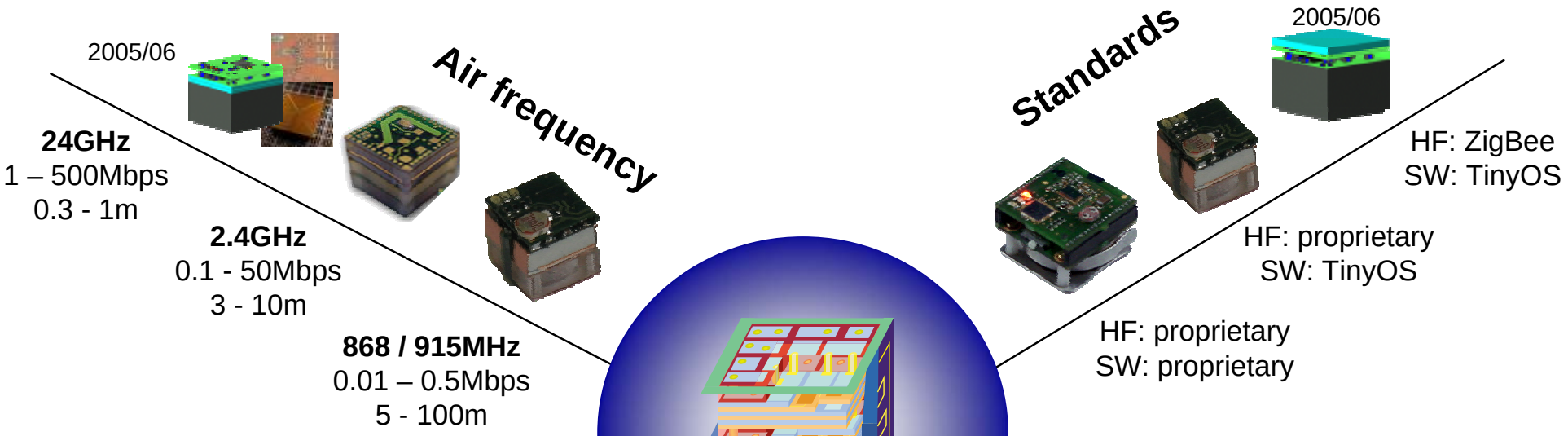
The Roadmap for Semiconductor Industries



Fraunhofer IZFP Institut Zerstörungsfreie Prüfverfahren

Advanced Electronics (AVT)

eGrain – Roadmaps IZM



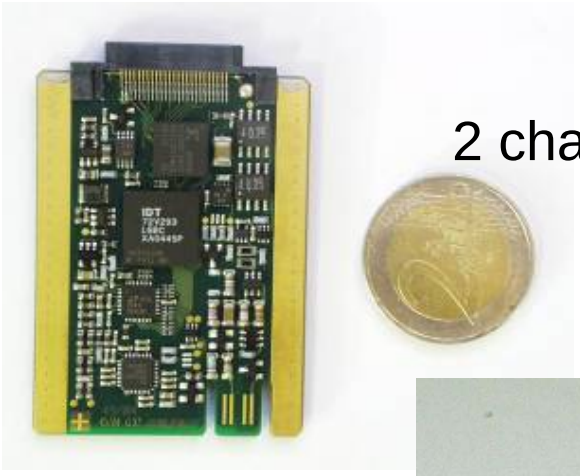
Standard-FR4	HDI-FR4	Flex	Flex	Chip Level	Wafer Level
TQFP, TSOP	CSP,µBGA,COB,FC	MCM-L	MCM-D	MCM-3D	MCM-3D
2 ... 3 cm	0.8 ... 2 cm	0.7 ... 1.5 cm	0.6 ... 1 cm	0.6 ... 0.5 cm	0.5 ... 0.45 cm

Nondestructive Evaluation: Sampling Phased Array Platform

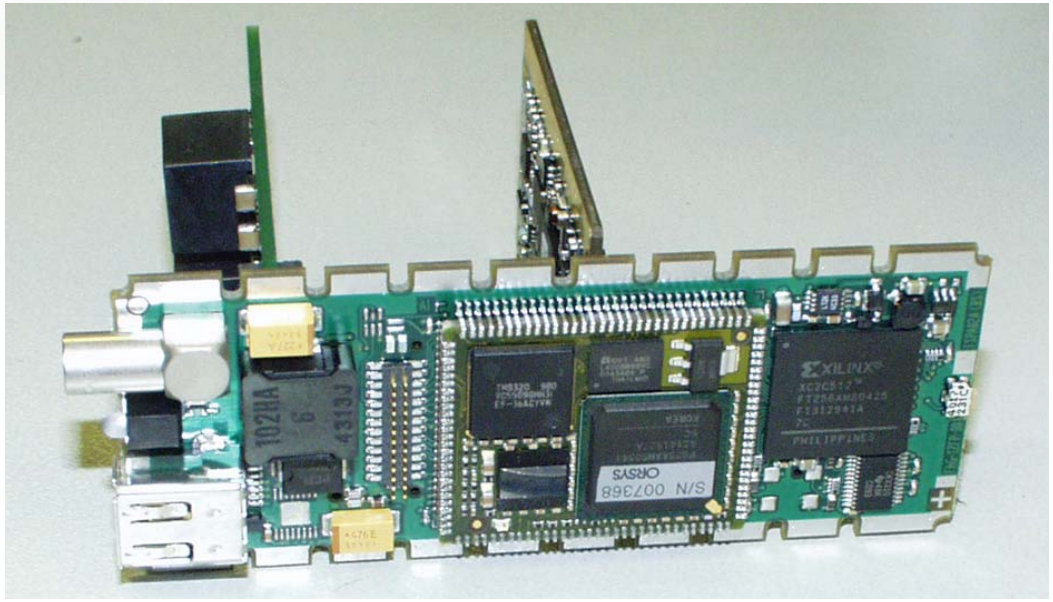
16-channel system, prototype

New 16-channel ultrasonic electronics µ-USE

Miniaturized Ultrasound Hardware



2 channels



Bus + channels

16-channel ultrasound system

Fraunhofer IZFP Institut Zerstörungsfreie Prüfverfahren

Progress in science and technology for SHM

Advanced sensor and NDE principles

Advanced electronics

➔ Advanced data acquisition and processing techniques

Embedded sensors

Distributed sensor systems and sensor networks

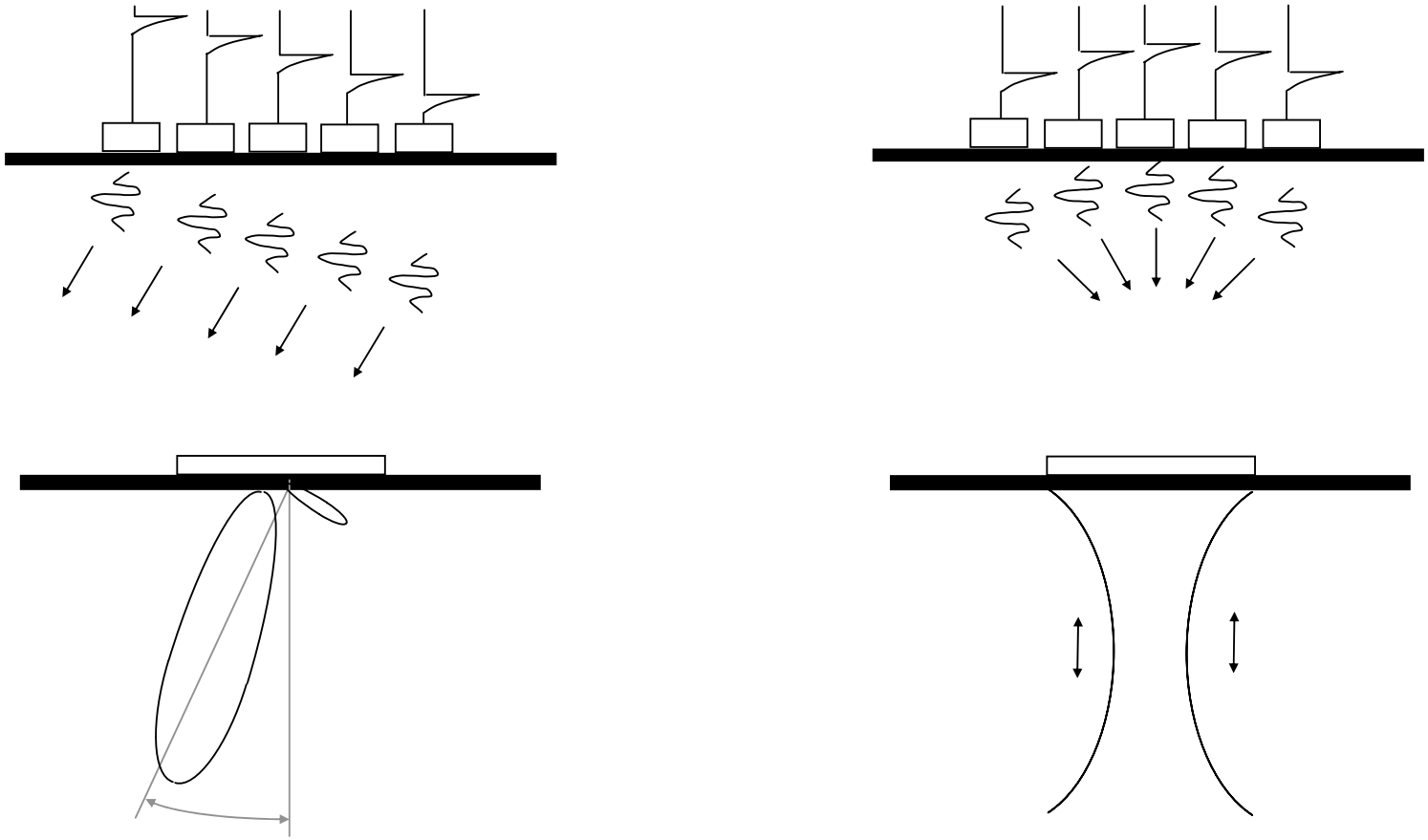
Telemetric systems

New concepts for power supply

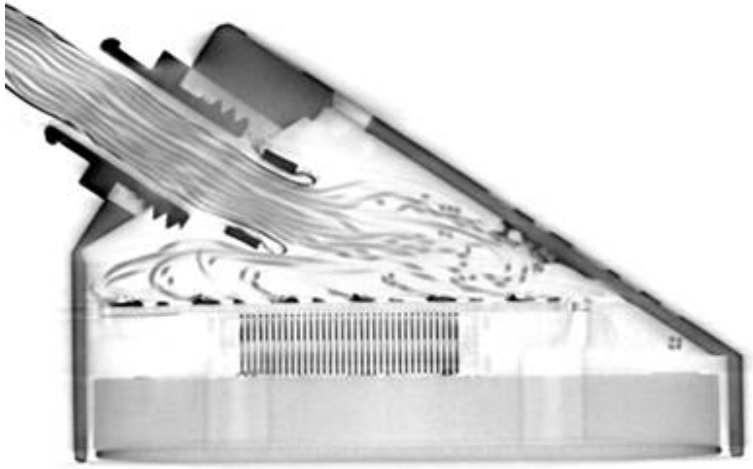
Monitoring of complex structures

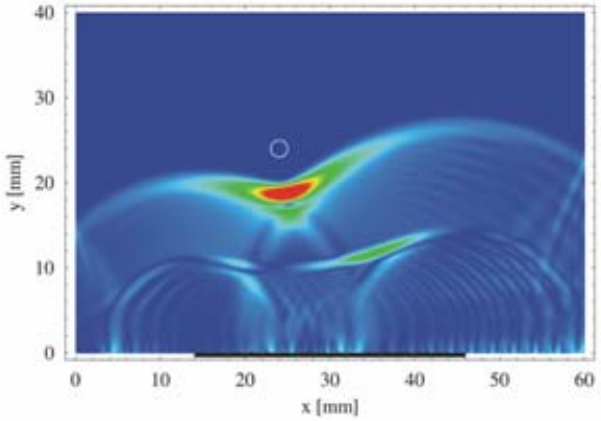
Fraunhofer IZFP Institut Zerstörungsfreie Prüfverfahren

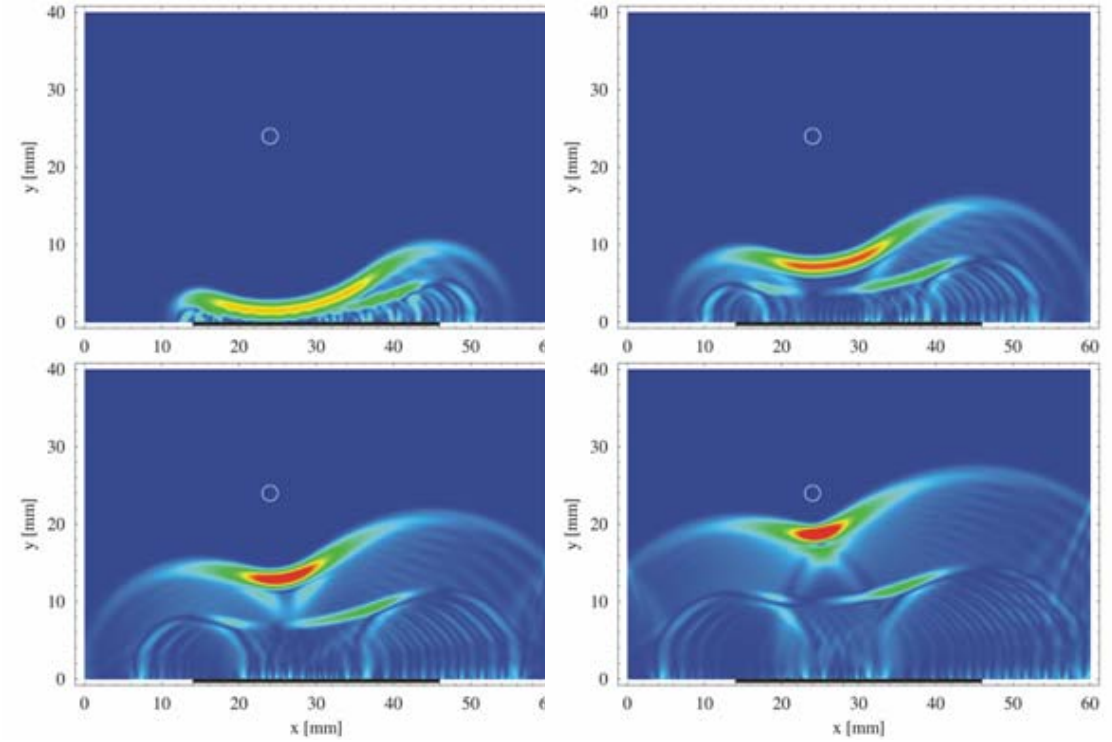
Phased Array Principle enables directing and focusing of sound fields



Phased Array Probe and Sound Field Modeling





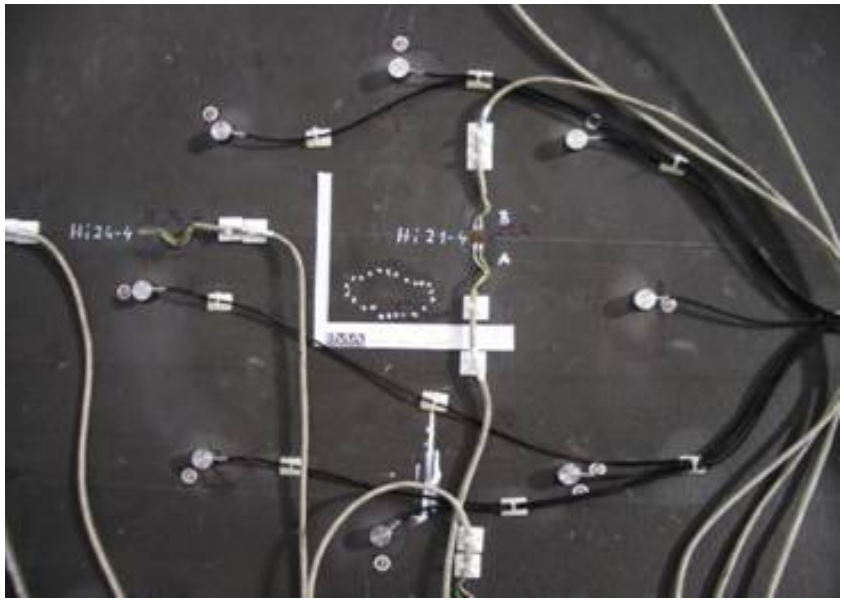


Numeric modeling of sound field for probe design

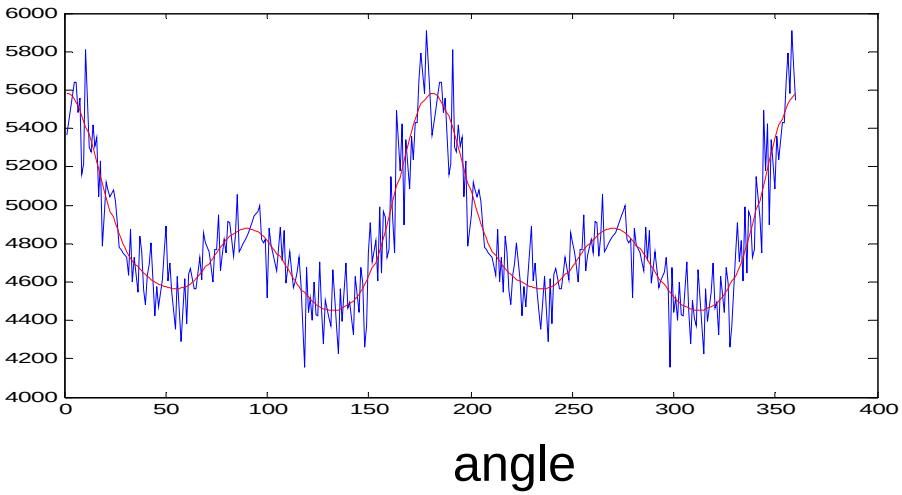
Fraunhofer IZFP Institut Zerstörungsfreie Prüfverfahren

Advanced Data Acquisition and Processing Techniques

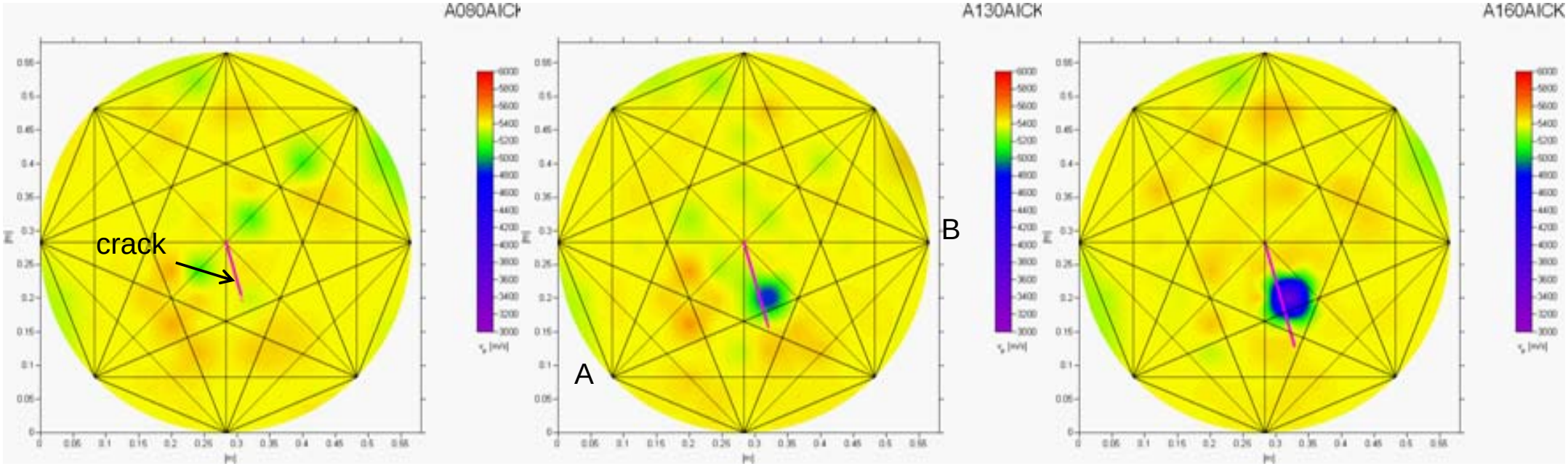
Instrumentation CFRP-Panels



Experimentally determined, angle dependent group velocity required for damage localization



Time of Flight Tomography



Fraunhofer Institut Zerstörungsfreie Prüfverfahren

Progress in science and technology for SHM

Advanced sensor and NDE principles

Advanced electronics

Advanced data acquisition and processing techniques

➔ Embedded sensors

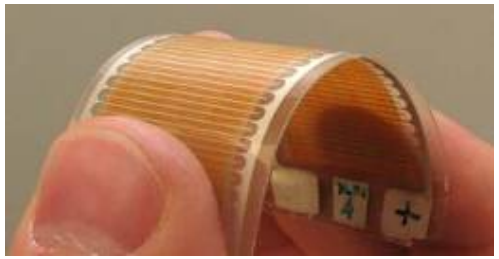
Distributed sensor systems and sensor networks

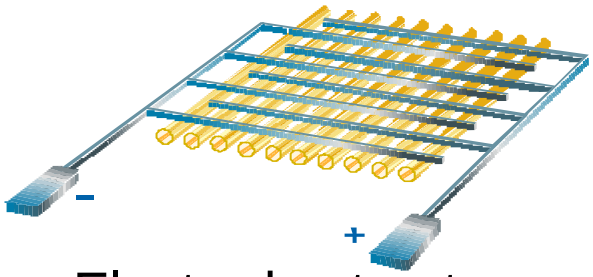
Telemetric systems

New concepts for power supply

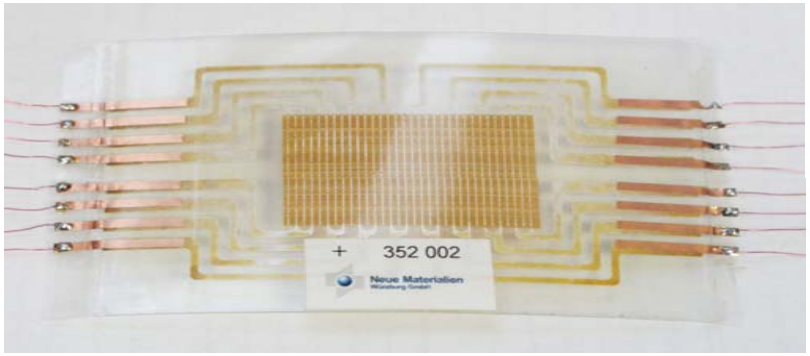
Monitoring of complex structures

Sensors based on PZT fibers





Electrode structure

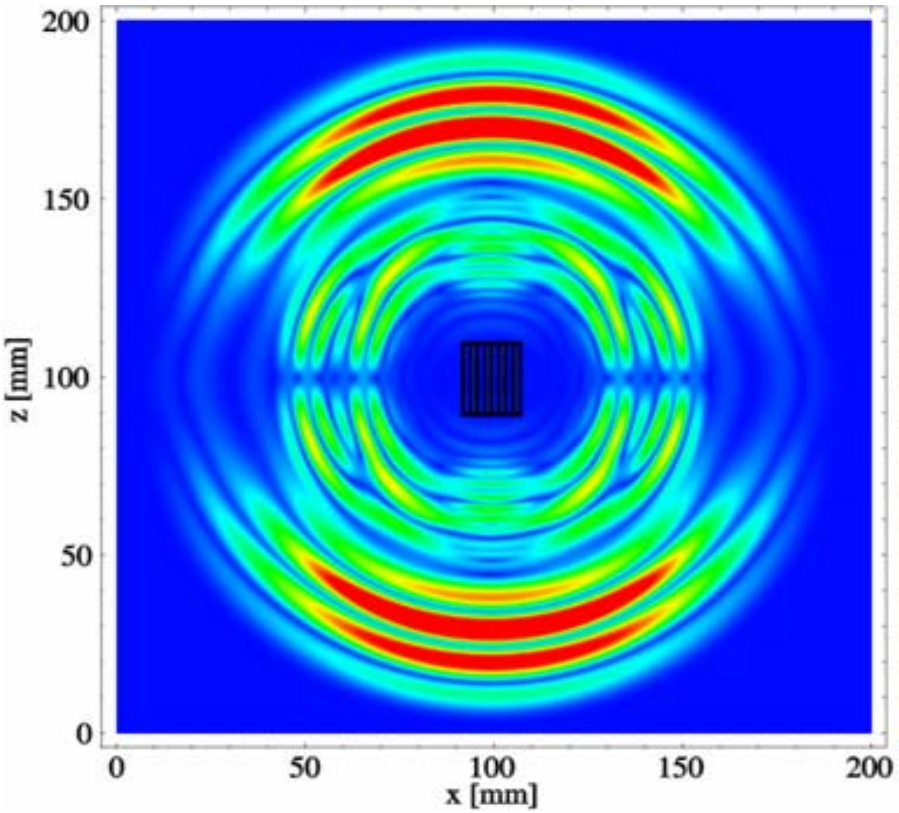


Mode selective signal detection

PZT fiber sensors integrated in the structure for impact detection

Fraunhofer LBF

Simulation of ultrasound excitation by PZT fiber transducers



200 x 200 x 1.5 mm³
Al plate

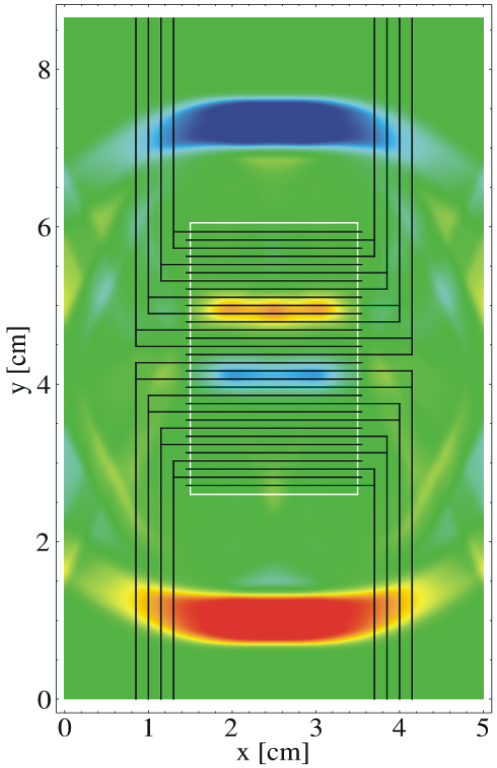
15 x 20 mm² fiber sensor

fibers vertically

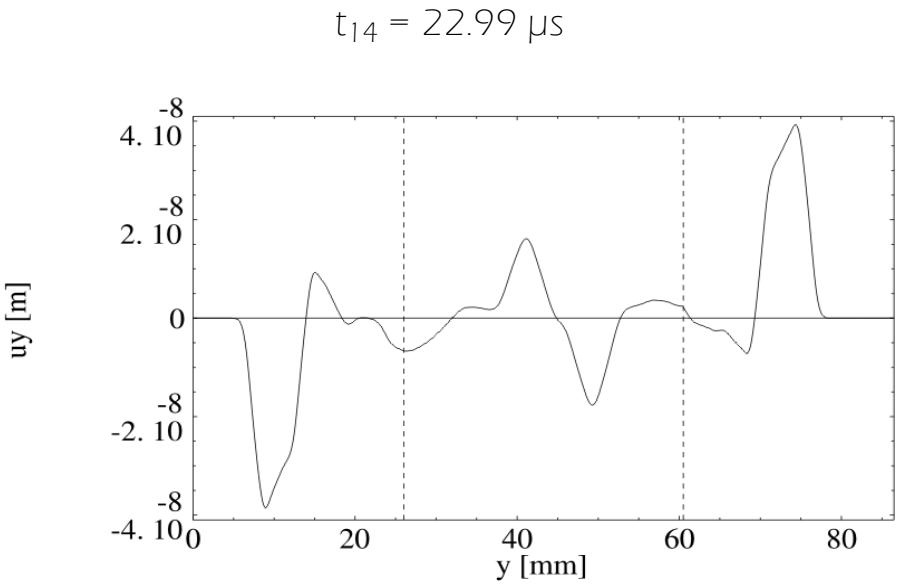
exciting frequency: 300 kHz

absolute value of the vector of particle velocity

Numerical simulation of symmetric Lamb wave propagation in a free fiber module caused by driving of one electrode pair



Wavefront snapshots



Displacement u_y at x = 2.5 cm

Progress in science and technology for SHM

Advanced sensor and NDE principles

Advanced electronics

Advanced data acquisition and processing techniques

Embedded sensors

➔ Distributed sensor systems and sensor networks

Telemetric systems

New concepts for power supply

Monitoring of complex structures

Fraunhofer IZFP Institut Zerstörungsfreie Prüfverfahren

Embedded Sensors

Sensor Node

Transducer

Sound
Acceleration
Pressure
Force

Analog Block

Analog Signal Processing

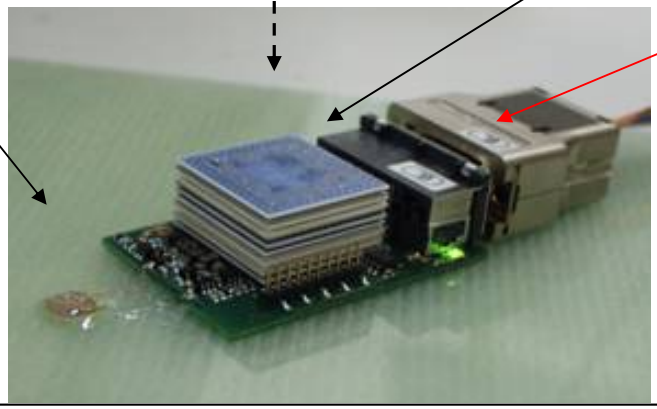
Waveform Generator

DSP-Block

Digital Signal Processor
Memory
Network Interface

Network

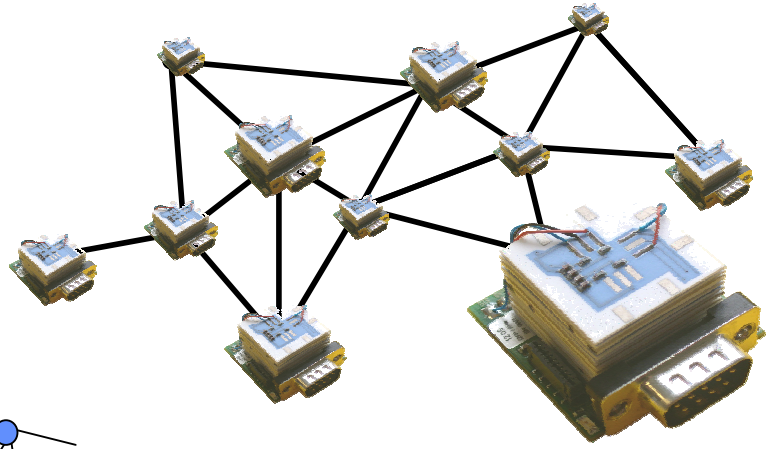
CAN
RS232
USB
Bluetooth

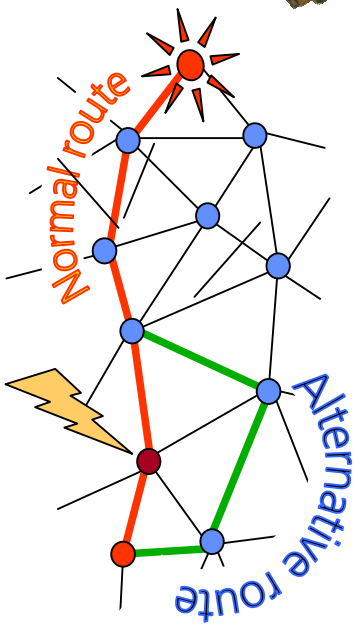


Fraunhofer IZFP Institut Zerstörungsfreie Prüfverfahren

Self Assembling Sensor Networks

- Data on demand / data in case of need
- Inter-sensor communication
  - Networked sensors
  - Integrity of the values (plausibility checks)
  - Bypassing/virtual replacement of defect sensors
  - Need of small transmission power





Bad knot can still be addressed:

Its value is interpolated by neighboring sensors of the same kind.

Fraunhofer IZFP Institut Zerstörungsfreie Prüfverfahren

Progress in science and technology for SHM

Advanced sensor and NDE principles

Advanced electronics

Advanced data acquisition and processing techniques

Embedded sensors

Distributed sensor systems and sensor networks

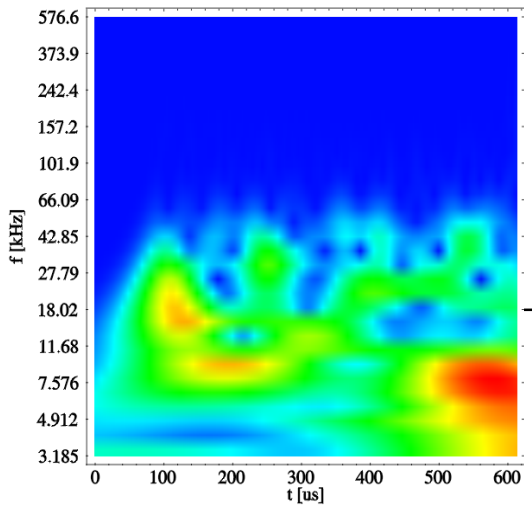
➔ Telemetric systems

New concepts for power supply

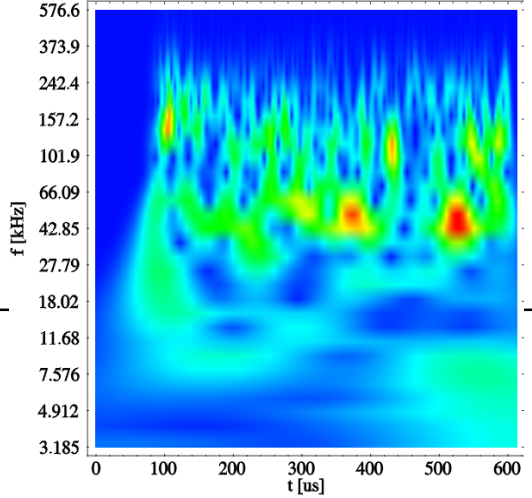
Monitoring of complex structures

Fraunhofer IZFP Institut Zerstörungsfreie Prüfverfahren

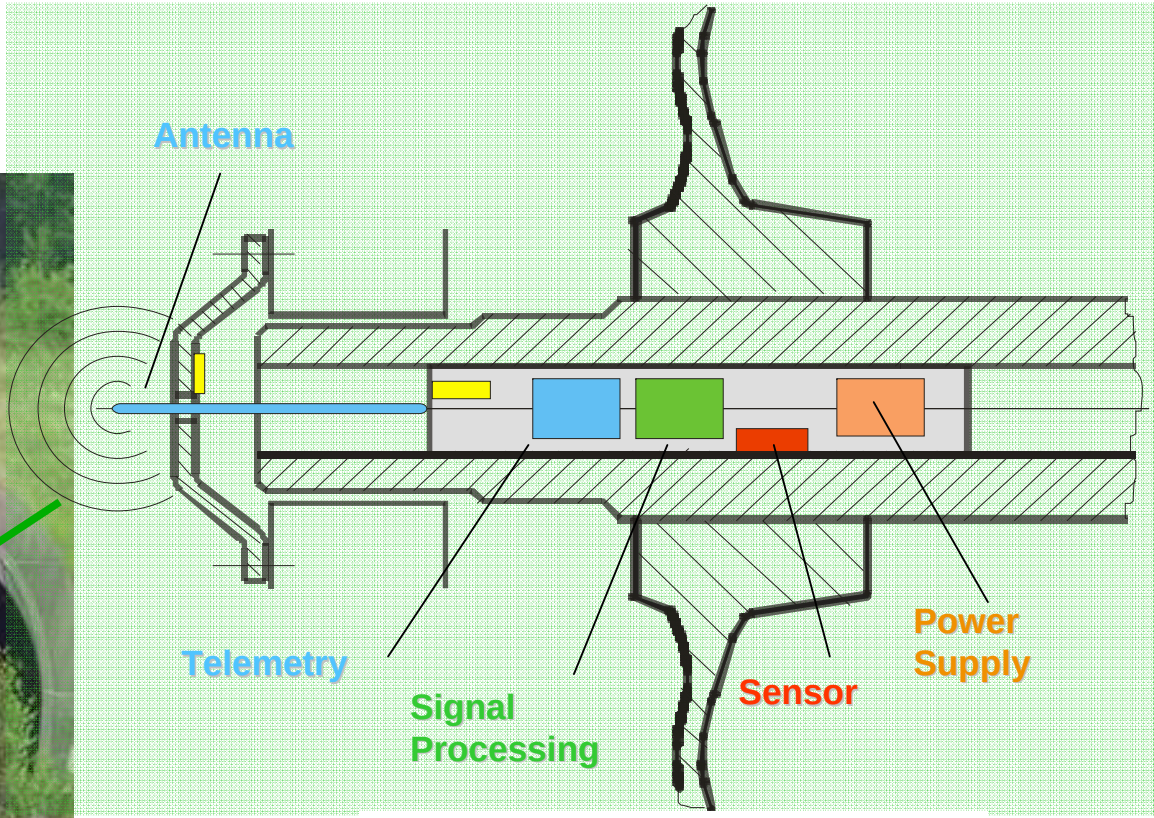
Sleeve Shaft Integrated Acoustic Real-time Monitoring



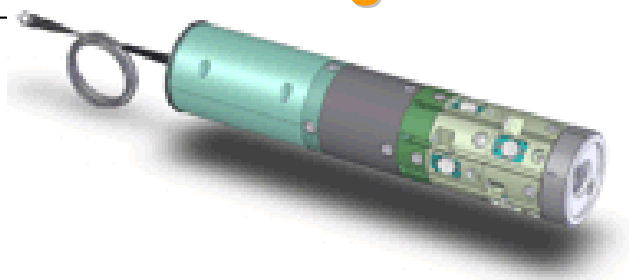
S = 2.0 mm



S = 0.25 mm



Monitoring Module:



Progress in science and technology for SHM

Advanced sensor and NDE principles

Advanced electronics

Advanced data acquisition and processing techniques

Embedded sensors

Distributed sensor systems and sensor networks

Telemetric systems

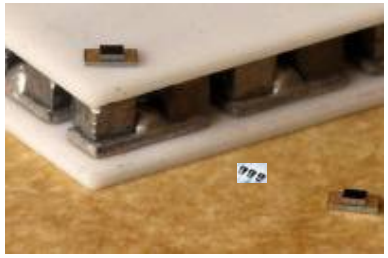
➔ New concepts for power supply

Monitoring of complex structures

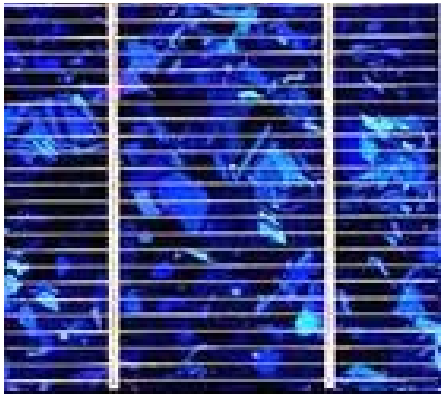
Fraunhofer IZFP Institut Zerstörungsfreie Prüfverfahren

New Concepts for Power Supply

Power Supply



Thermo-generators
(Fa. Micropelt / FhG IPM)

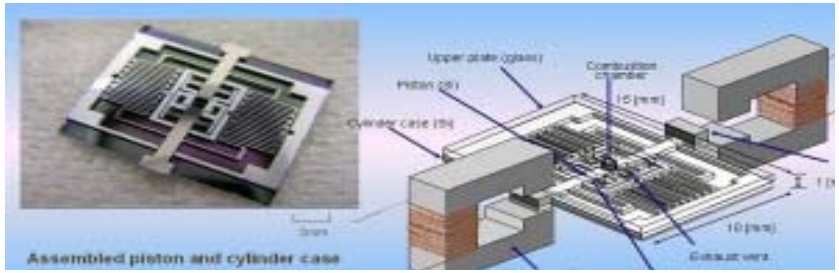


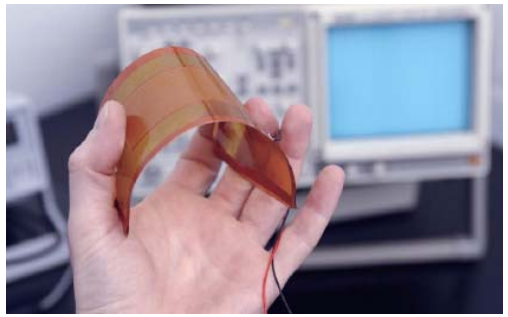
Solar cells
Solarwatt, Q-Cells

Inductive generators
(Fa. pro-micron)

Piezoelectric generators
(Fa. EnOcean / Siemens / FhG IKTS)

Kinetic generators
(Research Institute for Microsystem Technology, Ritsumeikan University)





Fraunhofer IZFP Institut Zerstörungsfreie Prüfverfahren

Progress in science and technology for SHM

Advanced sensor and NDE principles

Advanced electronics

Advanced data acquisition and processing techniques

Embedded sensors

Distributed sensor systems and sensor networks

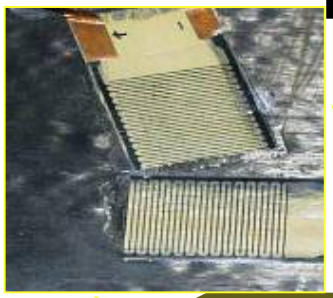
Telemetric systems

New concepts for power supply

➔ Monitoring of complex structures

Fraunhofer IZFP Institut Zerstörungsfreie Prüfverfahren

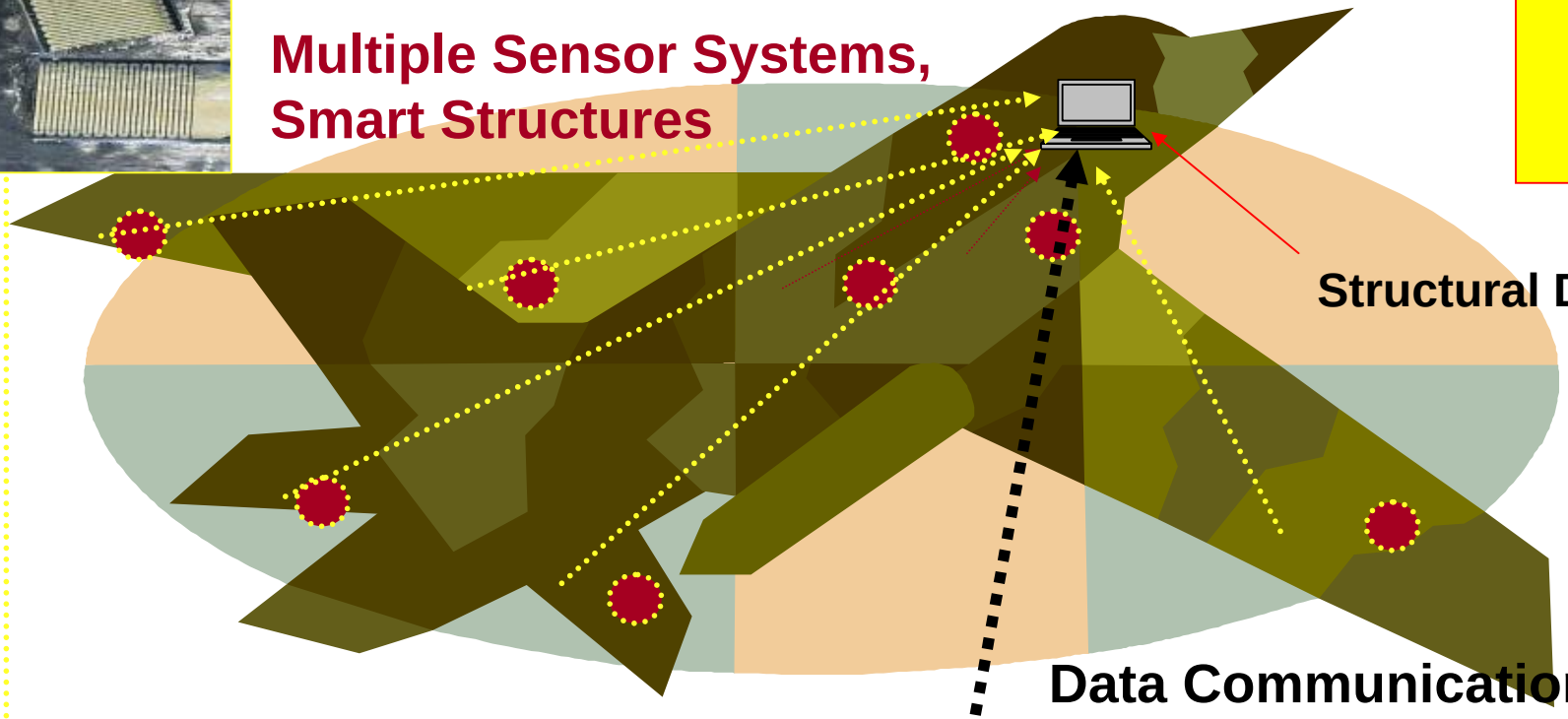
Monitoring of complex structures



Local Sensor Network

Condition Based Maintenance

Multiple Sensor Systems, Smart Structures

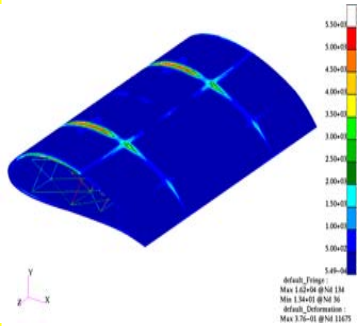


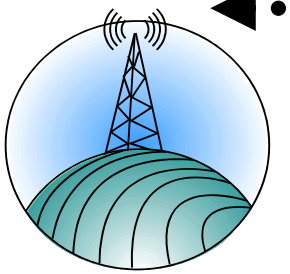
Structural Damage Indicator

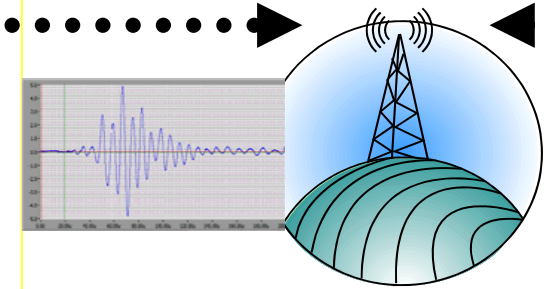
Data Communication

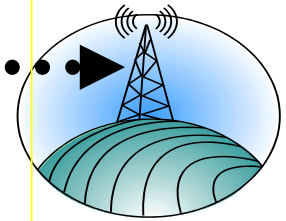
Communication

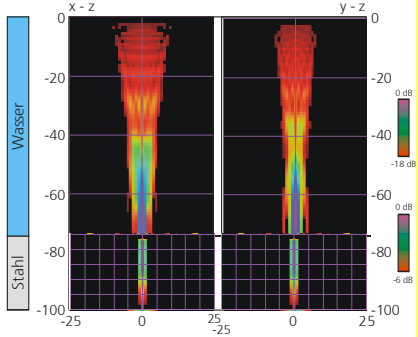
Communication











Structure Modeling
Damage Quantification

NDE Signal Analysis
Structure Integrity Doc.

NDE Modeling
Signal Interpretation

Airbus A380 Full Scale Fatigue Test

IABG mbH

Aircraft Structure Tests

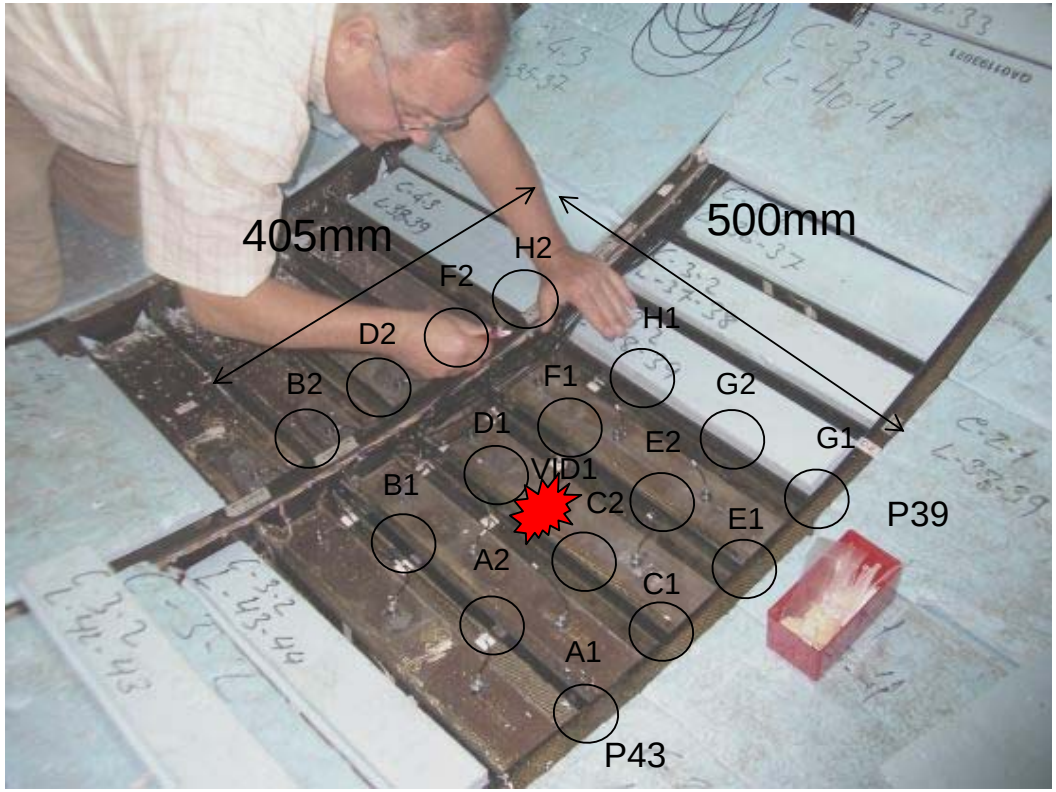
Dipl.-Ing. Felix Schwarberg

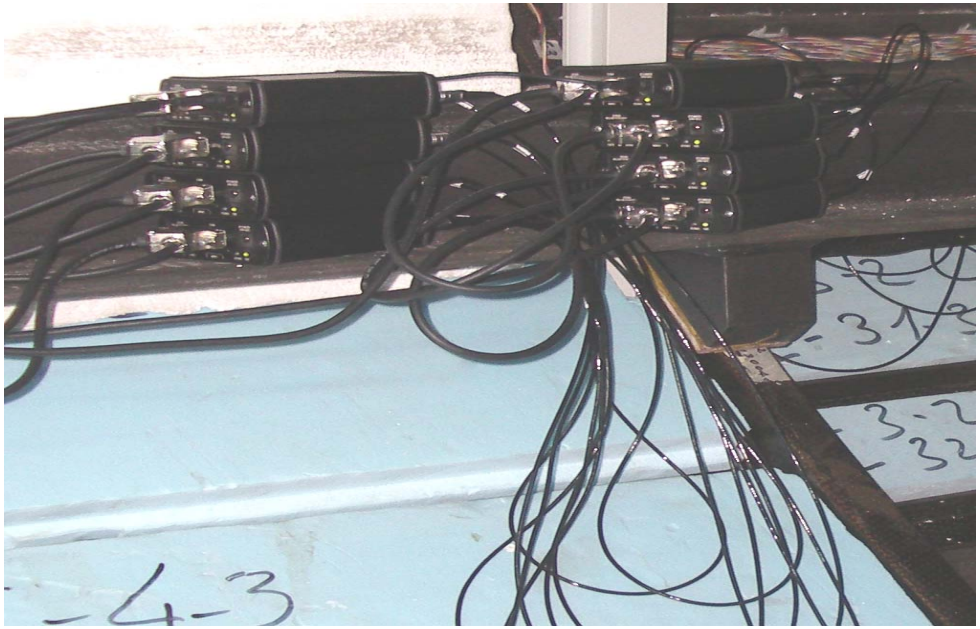
Zum Windkanal 17

01109 Dresden, Germany

IABG
DRESDEN

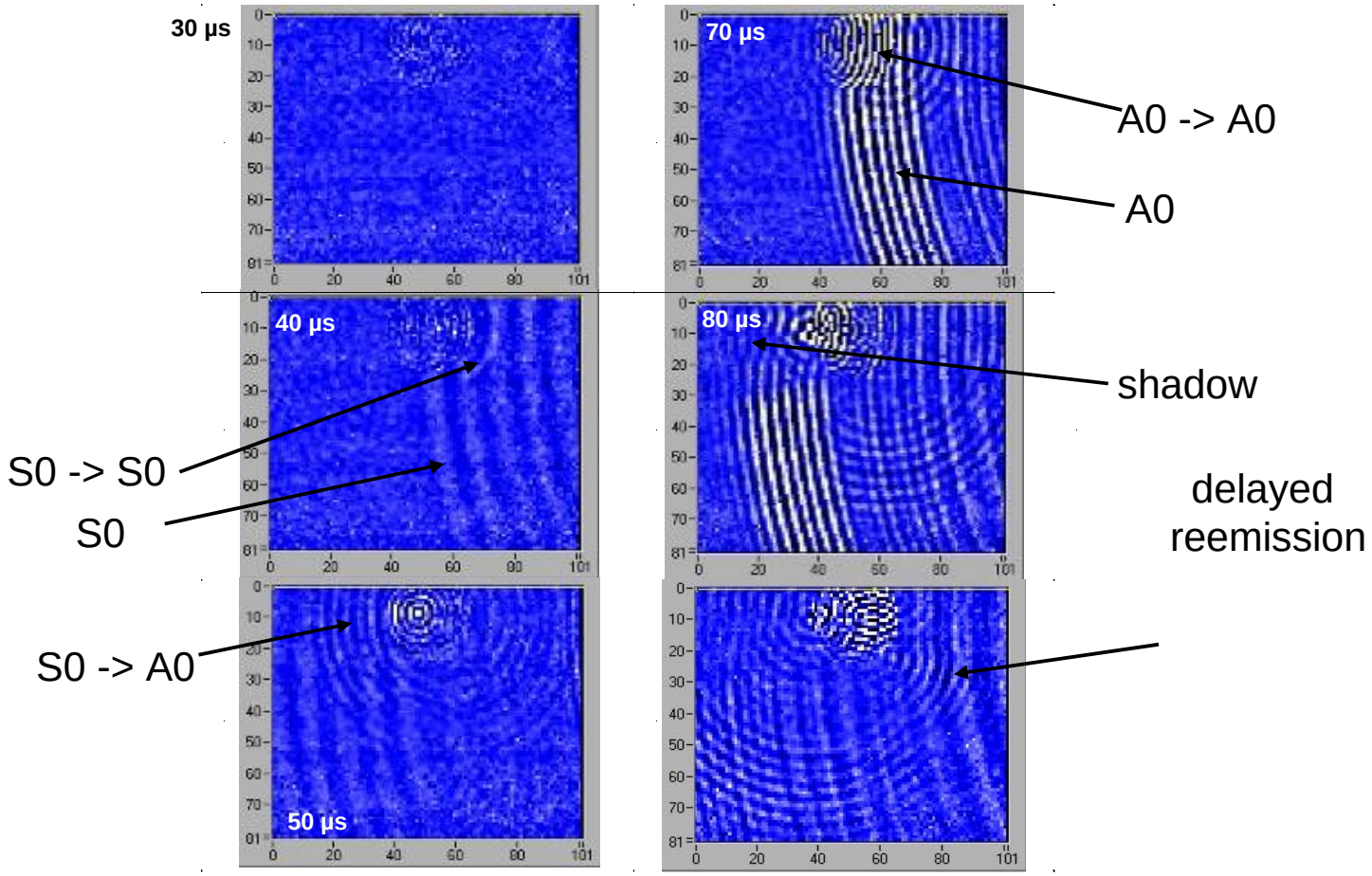
Instrumentation of Impact Test





Test is performed in Madrid (Spain)
Experiments are controlled from Dresden
online via Internet

Modeling of Lambwave / defect interaction to interpret signals

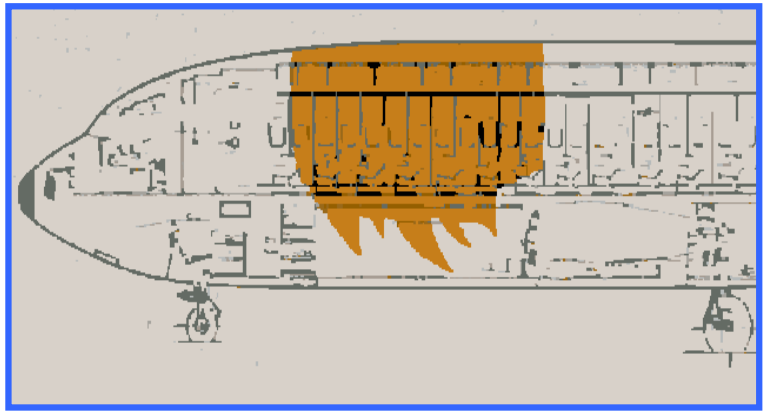


Fraunhofer Institut Zerstörungsfreie Prüfverfahren

Monitoring of Complex Structures

NDE in Aviation

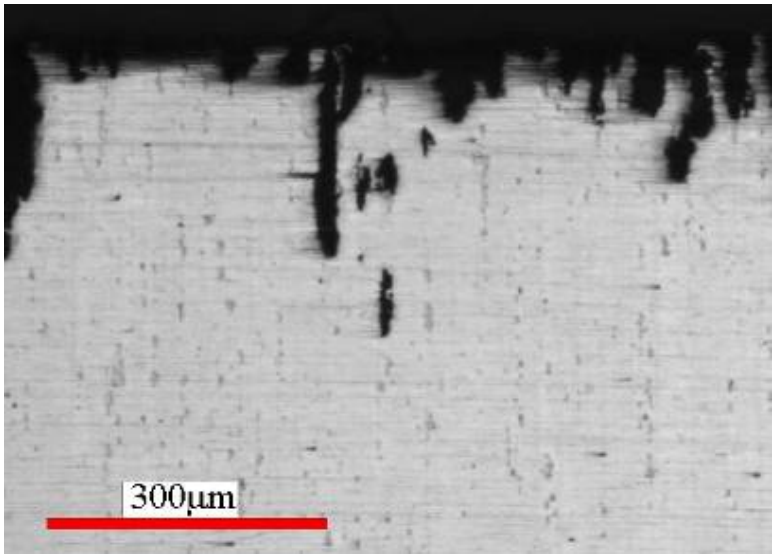
- Aloha Airlines flight
- corrosion damage led to widespread fatigue failure



Fraunhofer IZFP Institut Zerstörungsfreie Prüfverfahren

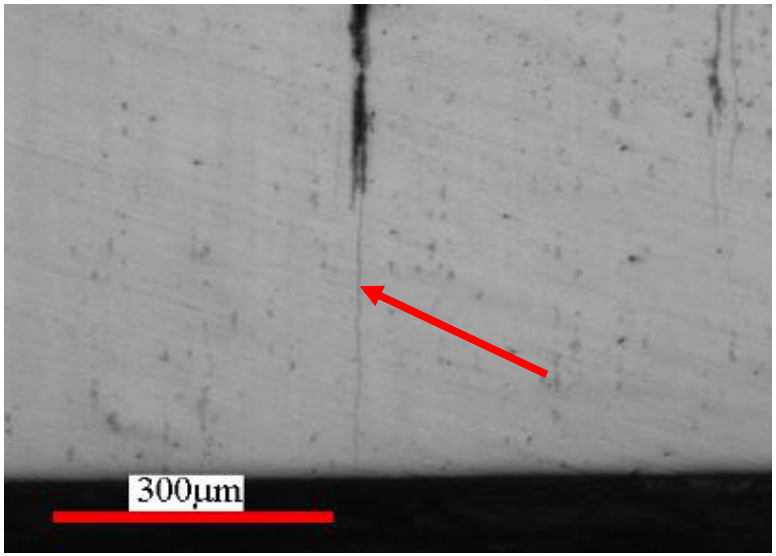
Monitoring of Complex Structures: IGC vs. Environment

AA7178 wingskin



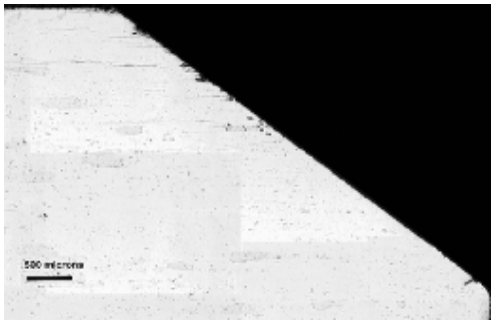
Electrochemical treatment in NaCl solution at anodic potential.

Selective grain attack.

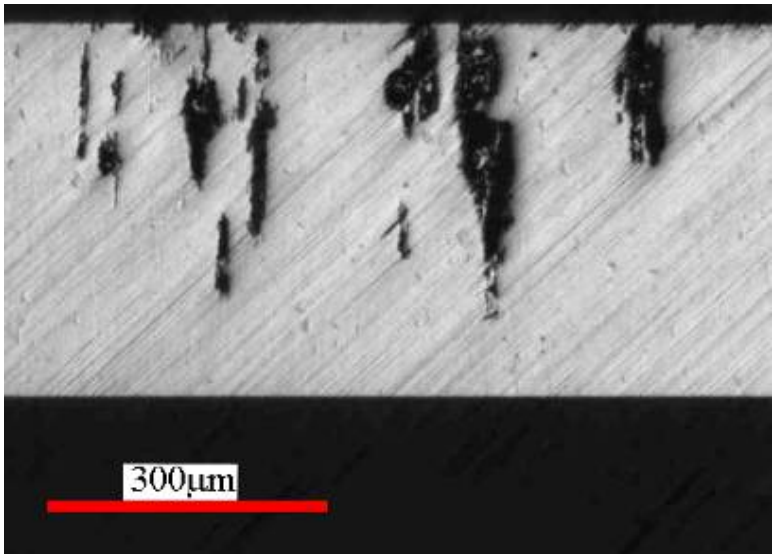


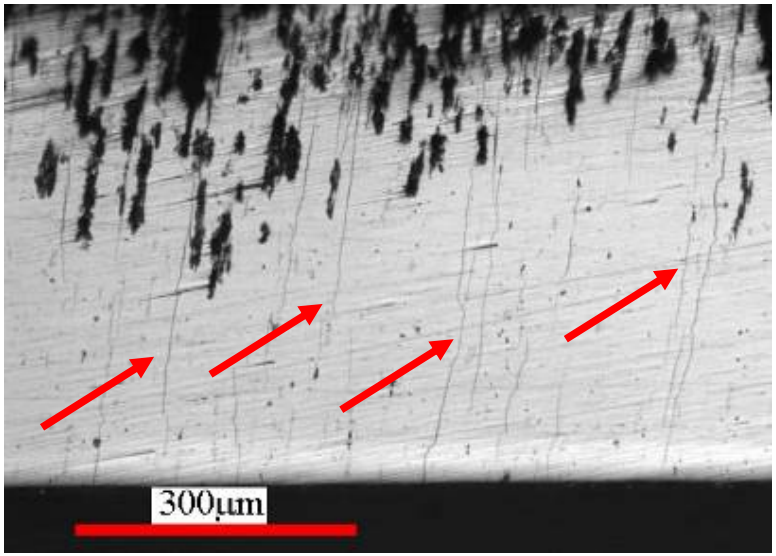
High humidity exposure after electrochemical pretreatment.

Sharp IGC fissures.



AA7075 plate





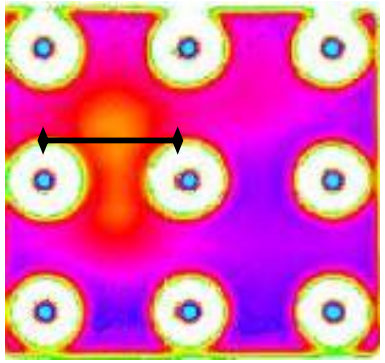
Worldwide Outdoor Exposure Testing for Environmental Severity

Fraunhofer IZFP Institut Zerstörungsfreie Prüfverfahren

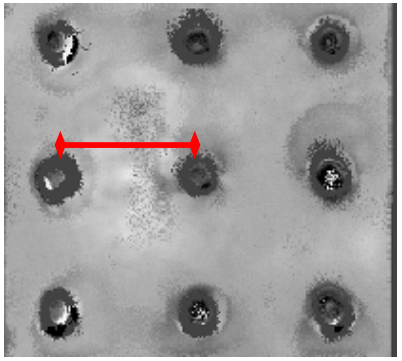
Evaluation of Corrosion Thinning in AA2024-T3 Lap Joint Structures

- Verification of MAUS IV Eddy Current Measurements

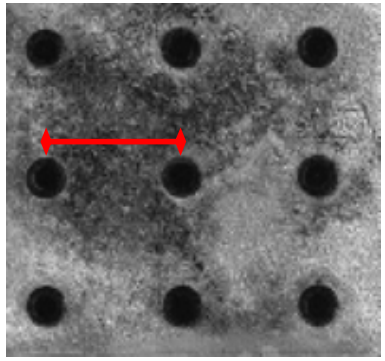
MAUS EC
f_A = 6 kHz
Thickness loss
both layers



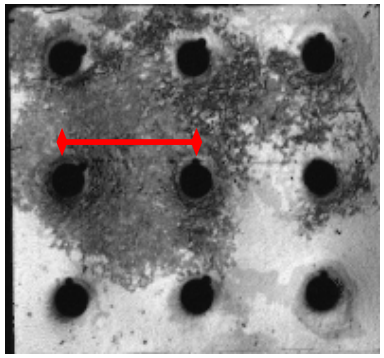
MAUS UT
f_A = 10 MHz
time-of-flight
top layer



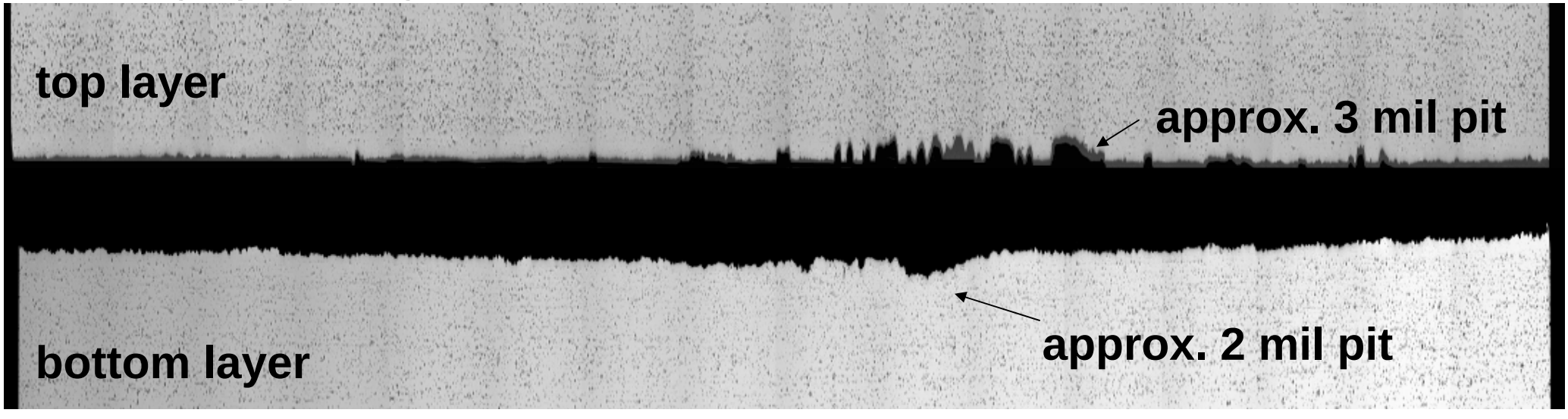
SAM
f_A = 25 MHz
signal scatter at corroded surface
top layer



bottom layer



metallography images:

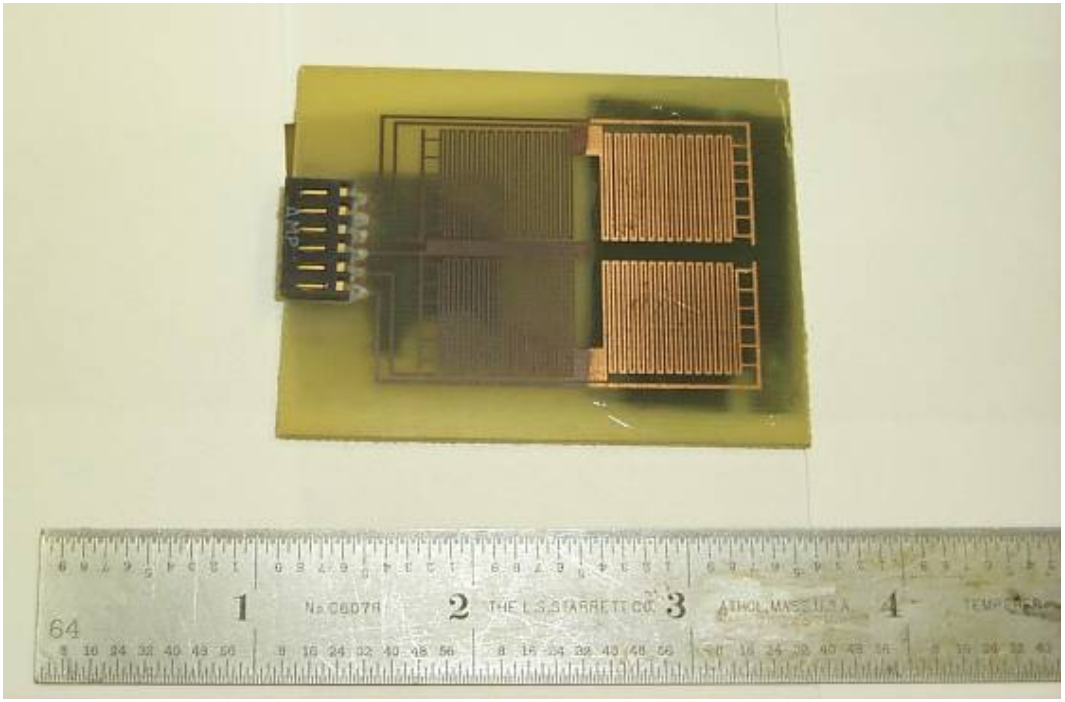


Worldwide Outdoor Exposure Testing for Environmental Severity

Long-term health monitoring objective

Sensor coverage of critical areas

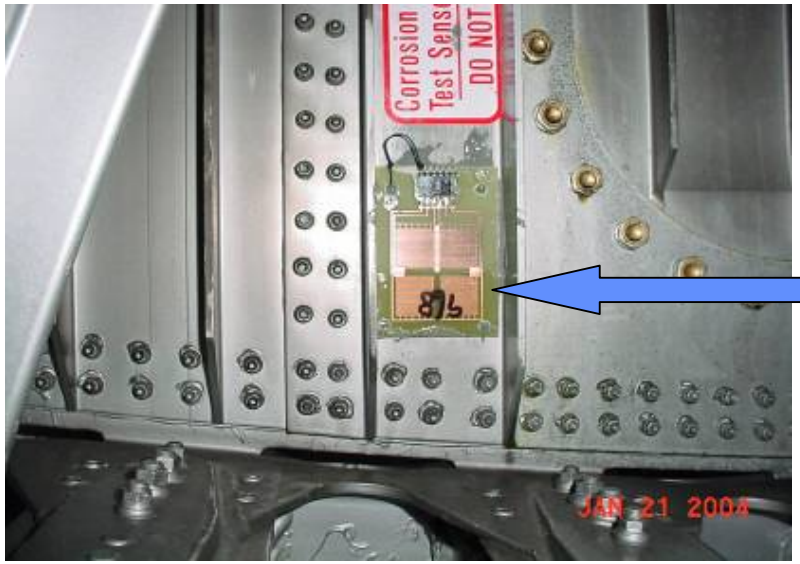
Growing need for a collective repository for sensor data



Courtesy
S&K Technology
Dayton, OH

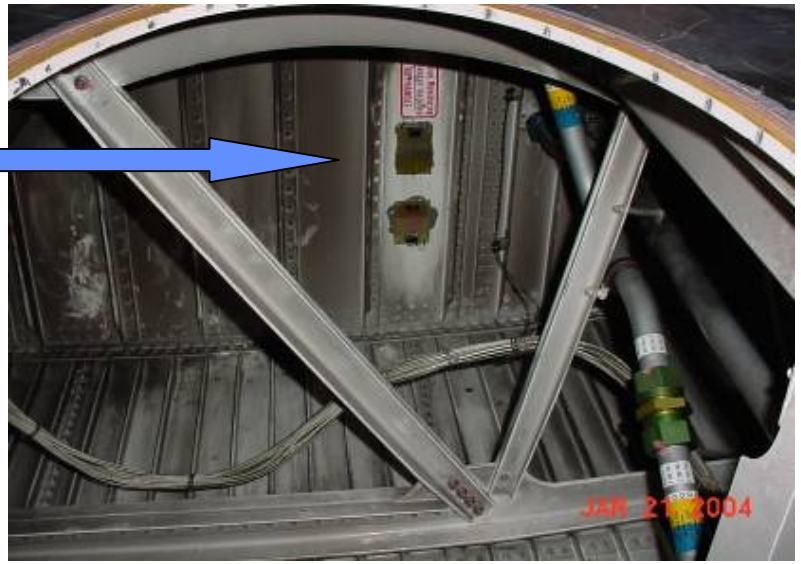
Monitoring of Complex Structures

Environmental Severity Sensors: Environmental Sensing



Rainbow Fitting

Engine Dry Bay



Right Sloping Longeron

Left MLG

Time frame for SHM implementation from Airbus Industries

SHM 1st Generation (local systems:

- Benefit: Maintenance costs / Human factor reduction
- Characteristic: Surface sensors / Alternative to conv. NDI (retrofit) / Local monitoring.

SHM 2nd Generation

- Benefit: +Weight Saving on component level
  Increased aircraft availability
  (postpone repairs/maintenance)
- Characteristic: On-line system
  Allows new design philosophy

SHM 3rd Generation

- Benefit: ++Global Weight Saving (incl. snowballs)
  Increased residual aircraft value
  Optimisation of system components positioning
- Characteristic: Fully integrated On-line system
  Allows new design philosophy

Courtesy
Speckmann
Airbus

Technology Readiness Timescale

AIRBUS

Application: Railroad

October 17th, 2000

Accident at Hatfield Station

4 passengers killed,
34 passengers with severe injuries

Source: The Guardian

Application: Railroad

Cause:
Crack in wheel set

High speed train accident in Eschede 101 people died

Monitoring of Complex Structures

Application: Railroad

Monitoring of the overhead line condition

Crack detection in wheels

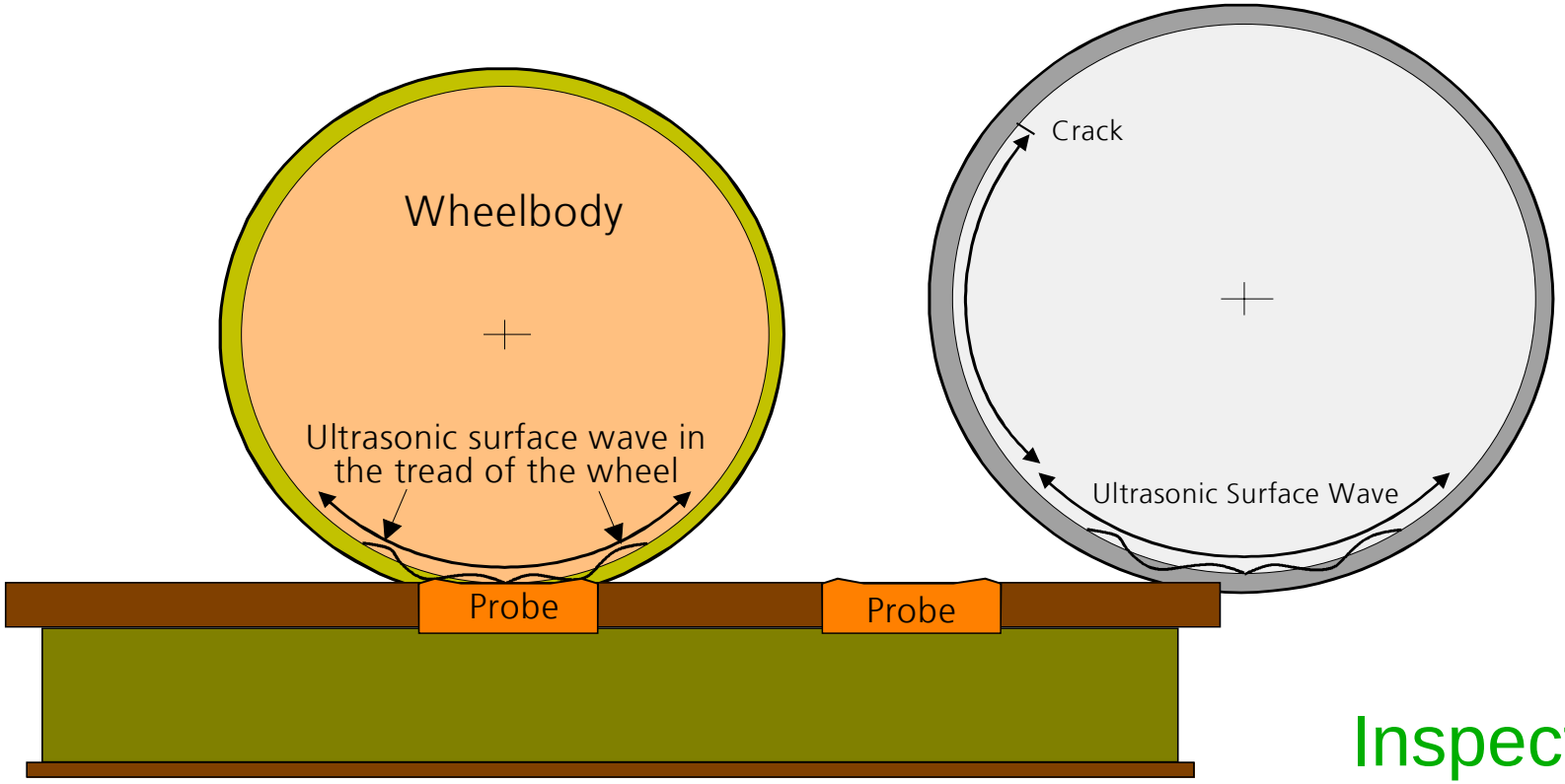
Crack detection in rails

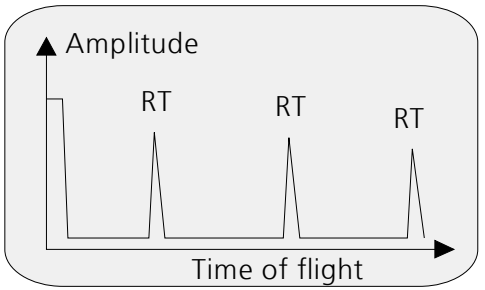
Fraunhofer IZFP Institut Zerstörungsfreie Prüfverfahren

Monitoring of Complex Structures

Condition Monitoring

In-motion inspection of the running surface of railway wheels by
Rayleigh waves using EMAT's and Guided Waves

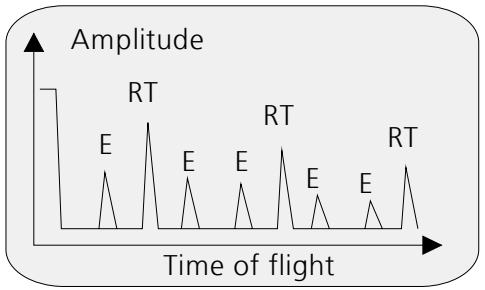




Tread in good condition

Ultrasonic A-Scan

Tread with defects



Inspection Principle

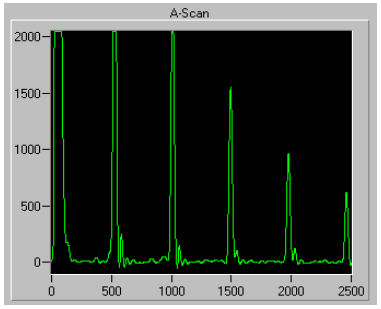
Fraunhofer IZFP Institut Zerstörungsfreie Prüfverfahren

Monitoring of Complex Structures

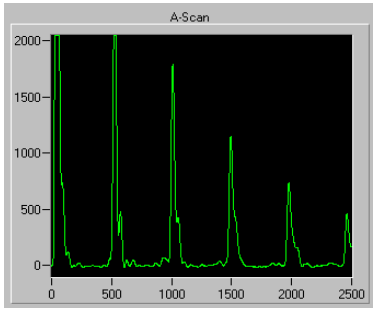
Condition Monitoring

In-motion inspection of the running surface of railway wheels by
Rayleigh waves using EMAT's and Guided Waves

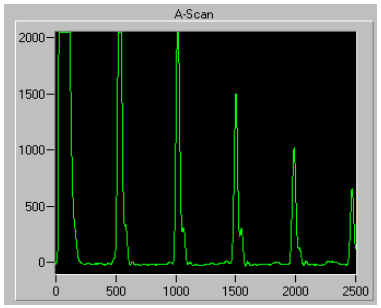
Train moving along the probes



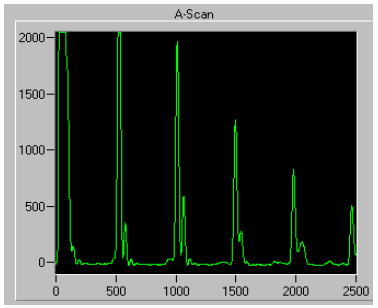
Probe 1



Probe 3



Probe 2



Probe 4

A-Scans of each of the four probes

Fraunhofer IZFP Institut Zerstörungsfreie Prüfverfahren

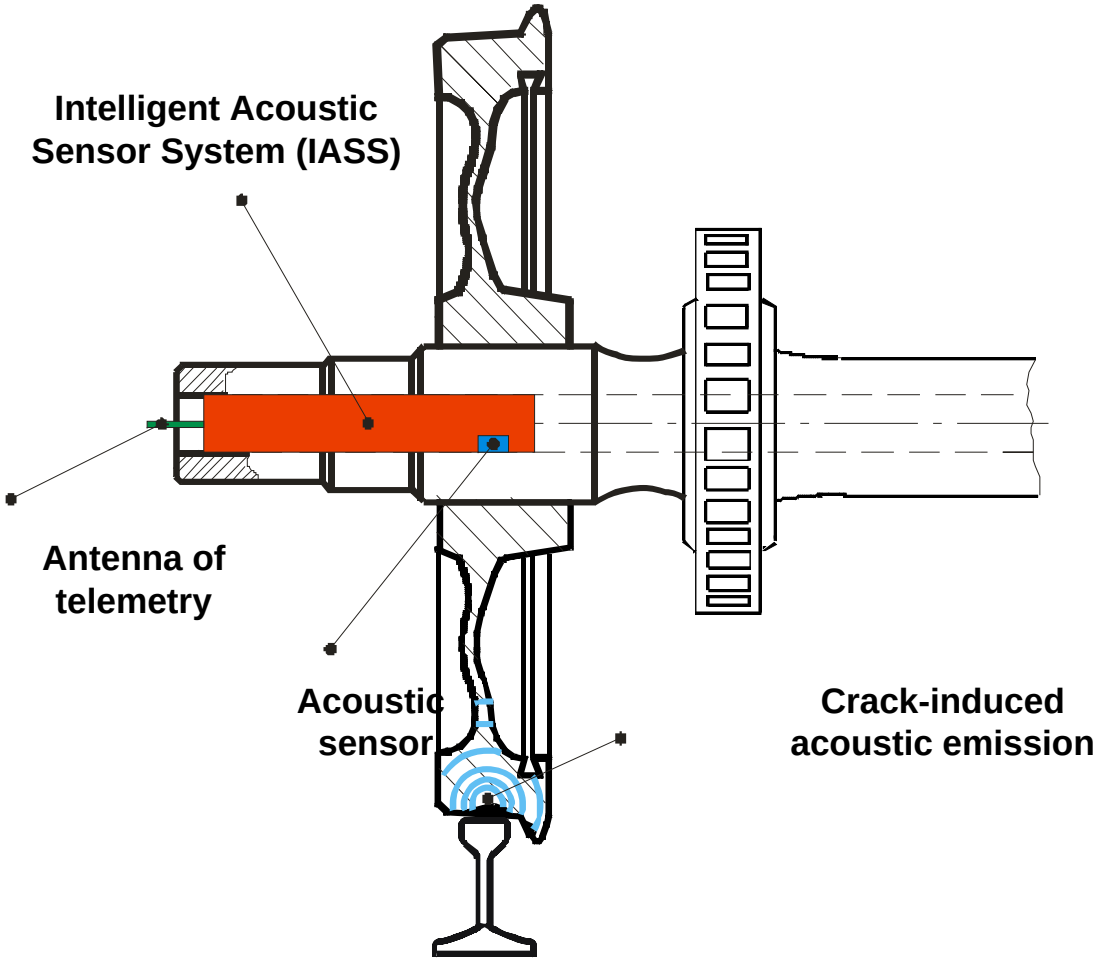
Application: Railroad, Health Monitoring

Modern concept:

Permanent health monitoring
by integrated
smart acoustic sensors

Properties:

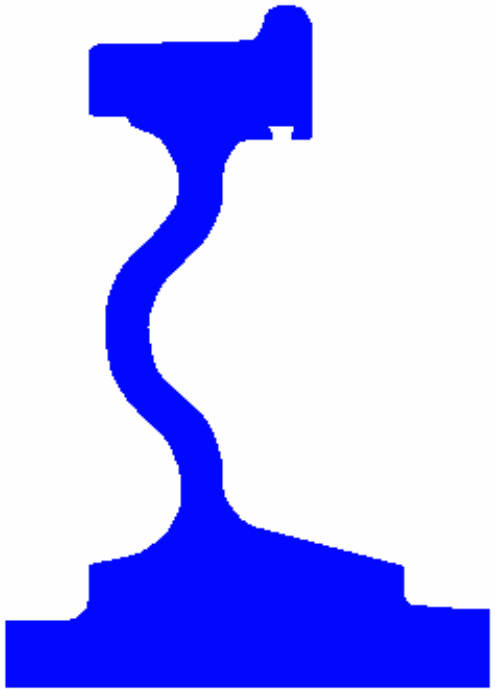
- Sensors integrated into the rotating shaft
- Data reduction within sensors
- Telemetric transmission



Fraunhofer IZFP Institut Zerstörungsfreie Prüfverfahren

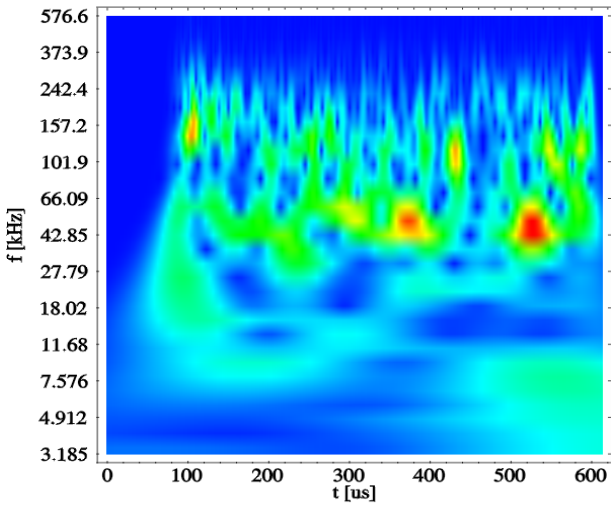
Application: Railroad, Health Monitoring

Modeling helps to understand wave generation and propagation as part of the sensing principle



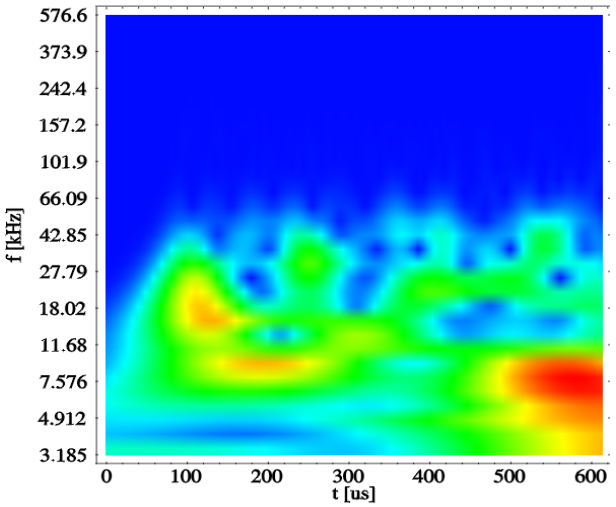
Calculated sonograms

narrow crack (0.25 mm)



S = 0.25 mm

wide crack (2.0 mm)



S = 2.0 mm

Fraunhofer IZFP Institut Zerstörungsfreie Prüfverfahren

Application: Railroad, Health Monitoring

Smart Sensor, ready for assembly into the shaft

- Sensing Element
- Trigger Module
- Signal Processing Module
- Power Module
- Telemetry Module

Fraunhofer IZFP Institut Zerstörungsfreie Prüfverfahren

Roadmap for Continuous Monitoring of High Speed Trains

2010

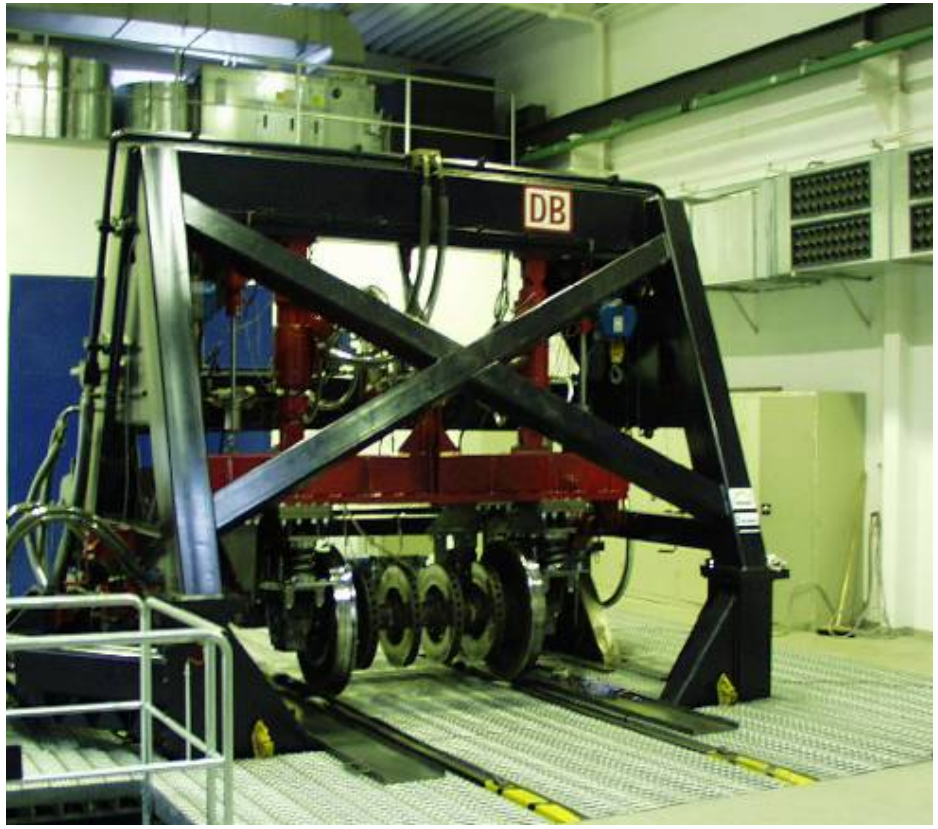
2009 Wheel inspection systems ready for all high speed trains

2007 Implementation of test of industrial prototypes at all wheel of ICE 3

2004 Laboratory prototypes ready

2000

1995 Test of sensors for wheel sets



Fraunhofer Institut Zerstörungsfreie Prüfverfahren

Neue Konzepte für Bauteil- und Materialüberwachung in der Verkehrstechnik, speziell Bahn und Flugzeug

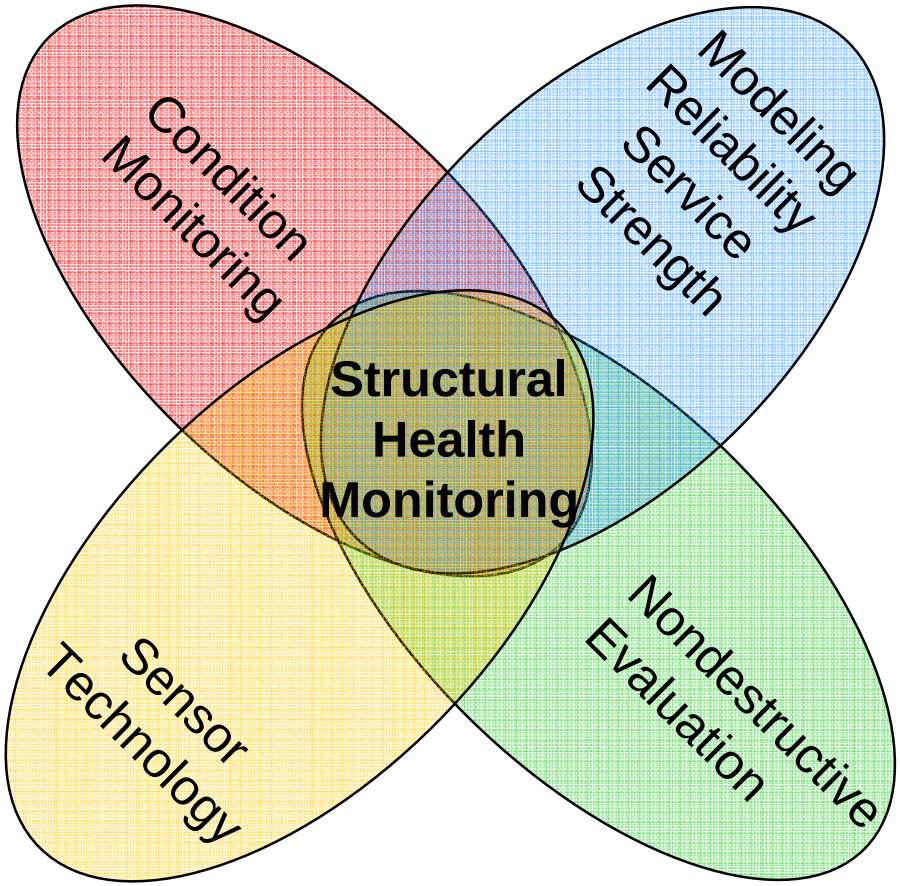
Outline

- The dawn of a new technology age
- Progress in science and technology for SHM
- SHM - A new discipline in technology
- Attempt of a prognosis

Fraunhofer IZFP Institut Zerstörungsfreie Prüfverfahren

SHM - A new discipline in technology

Resources for Structural Health Monitoring: Sensor Technology



+ Service/Maintenance

➔Condition Based Maintenance

➔Structural Health Management

+ Adaptive Control

➔Smart Structures

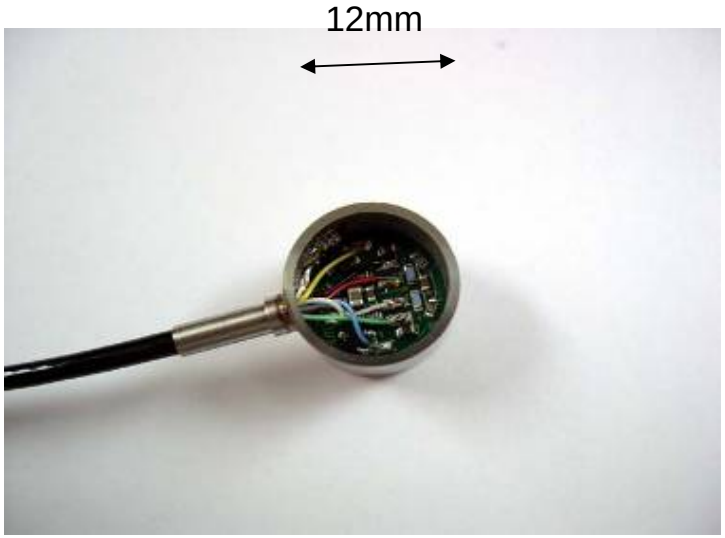
➔Reduction of degradation

➔Structural Health Control© LBF

Fraunhofer IZFP Institut Zerstörungsfreie Prüfverfahren

Resources for Structural Health Monitoring: Sensor Technology

Sensor systems with integrated electronics



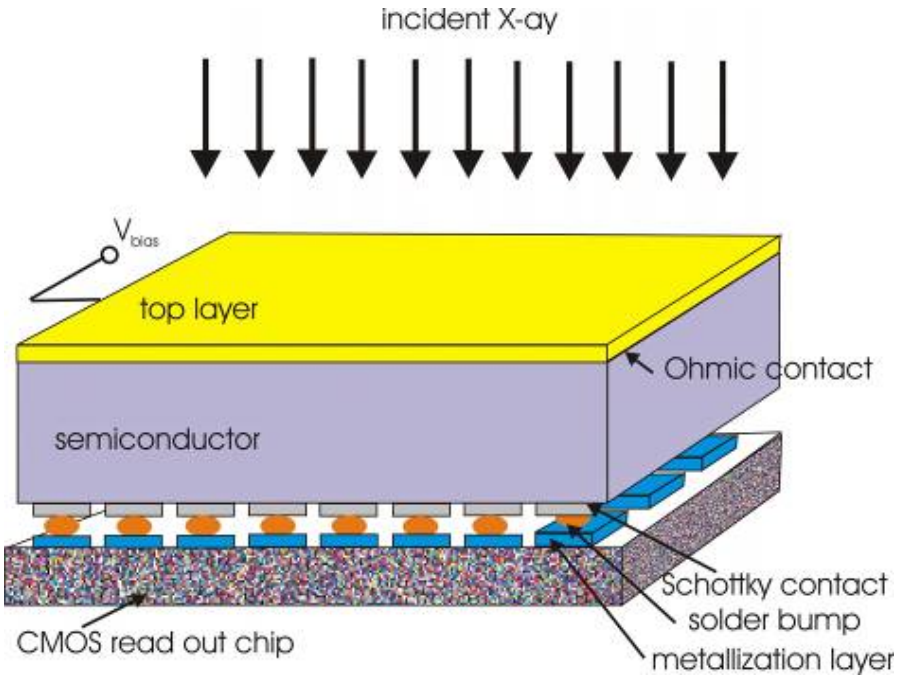
Integrated 40dB preamplifier
FKSE01B

Impact detection system based on Match-X standard CAN-Bus network

SHM - A new discipline in technology

Resources for Structural Health Monitoring: Sensor Technology X-ray Imaging

GaAs detector array



Photon counting energy sensitive readout

Medipix, CERN

Fraunhofer IZFP Institut Zerstörungsfreie Prüfverfahren

SHM - A new discipline in technology

Resources for Structural Health Monitoring: Sensor Technology

To be measured

- Temperature
- El./Magnetic fields and radiation
- Pressure, Force,
- Vibration, Acceleration
- Voltage, Current
- Chem. Composition
- Damage Processes (corrosion)

Sensor principles

- Resistance/ Conduct.
- Piezoelectricity
- Thermoelectric effect
- Electric induction
- Photoelectric effect
- Spectroscopy
- El. /mag. noise

….

Transformation of chemical and physical quantities into electric signals

Monitoring of
loading conditions
Distances and locations
Environmental parameters
Active degradation processes

Recent Trends: Intelligent sensors with incorporated signal analysis, date storage and power management
Multi-sensors and sensor networks
Self calibration and self diagnosis
Miniaturization and energy independence

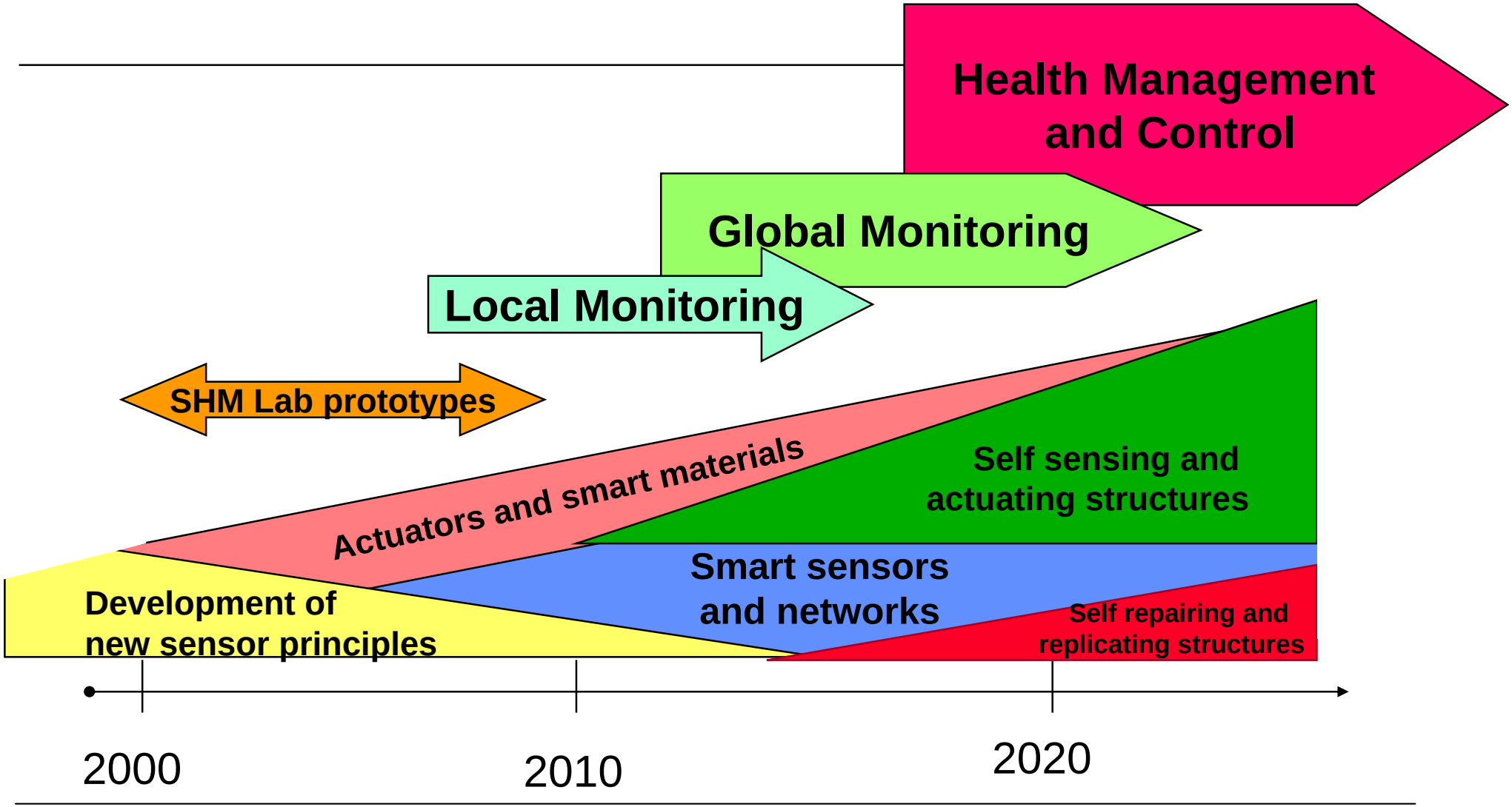
Neue Konzepte für Bauteil- und Materialüberwachung in der Verkehrstechnik, speziell Bahn und Flugzeug

Outline

- The dawn of a new technology age
- Progress in science and technology for SHM
- SHM - A new discipline in technology
- Attempt of a prognosis

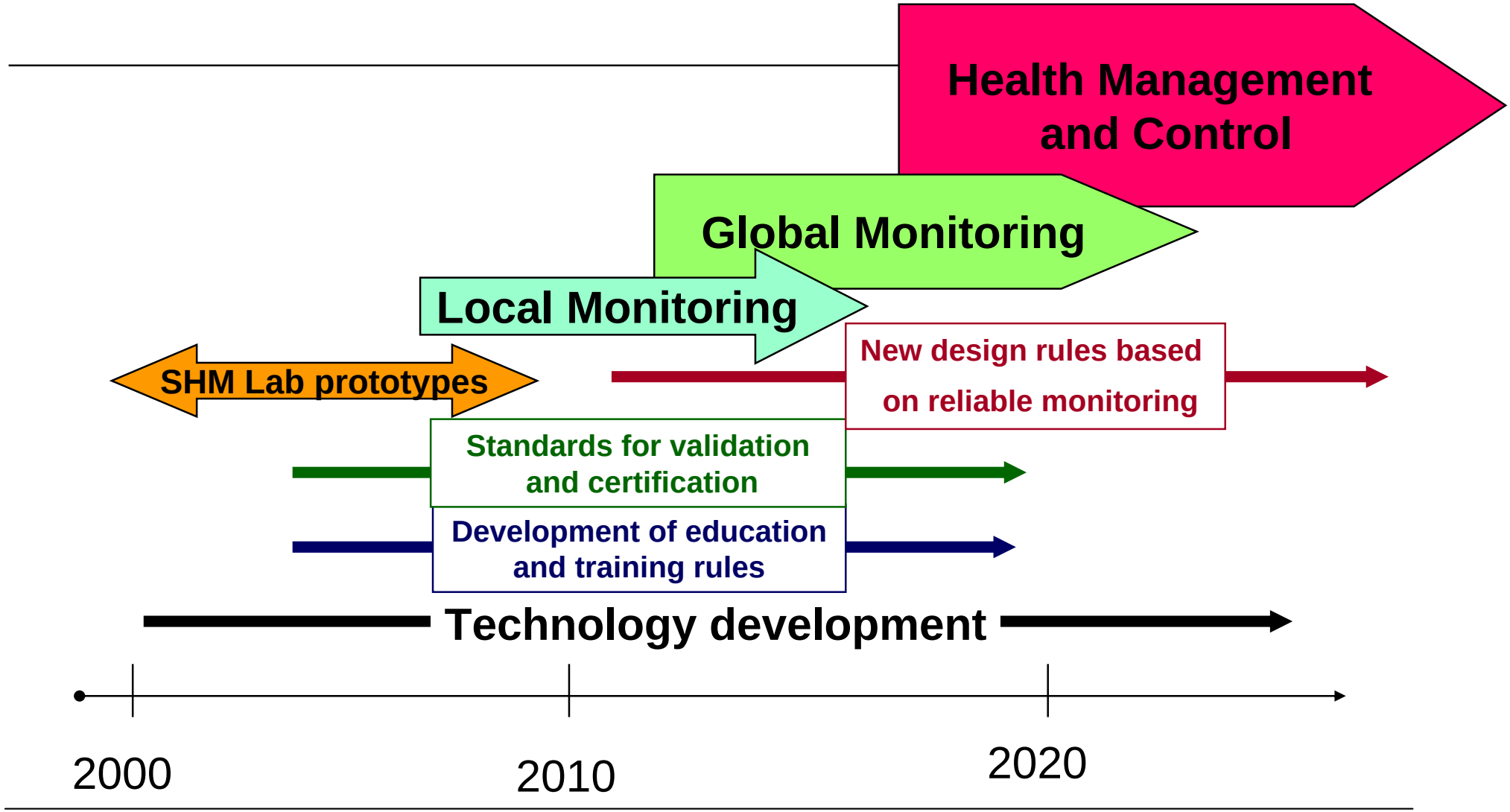
Fraunhofer IZFP Institut Zerstörungsfreie Prüfverfahren

Attempt of a Prognosis Technology



Fraunhofer IZFP Institut Zerstörungsfreie Prüfverfahren

Attempt of a Prognosis Management



Fraunhofer IZFP Institut Zerstörungsfreie Prüfverfahren

2nd Dresden Airport Seminar

Reliability, Testing, Monitoring of Aerospace Components

November 15, 2006

www.izfp-d.fraunhofer.de

Invited papers will be presented by

Dr. George Y. **Baaklini**, Chief, Optical Instrumentation and NDE Branch, NASA Glenn Research Center, USA

Theo **Hack**, EADS, Germany

Prof. Xiaoyan **Han**, Department of Electrical and Computer Engineering, Wayne State University, USA

Dr. Henrik **Rösner**, Airbus, Germany

Felix **Schwarberg**, IABG Industrieanlagen-Betriebsgesellschaft mbH, Germany

Dr. Paul **Wilcox**, University of Bristol, UK

Location:
Airport Dresden, Terminal 2