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# Space Qualification of a Fiber Optic Sensor System for X-38 Vehicle


**Arnd Reutlinger**

**Project Manager Fiber Optic Systems**


**Oktober 5th, 2005**

# Content

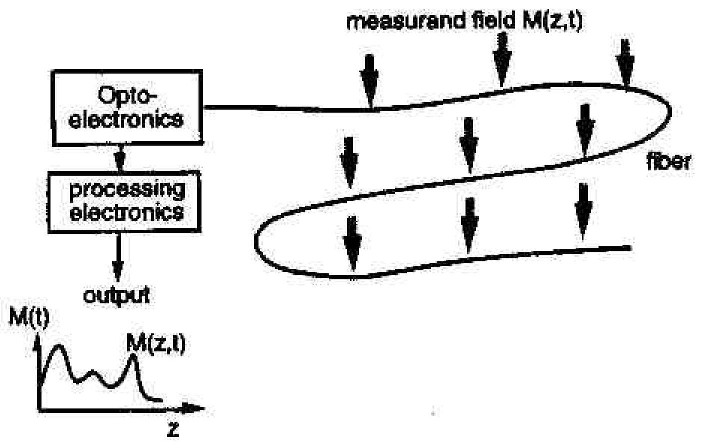
- Introduction into Fiber Optic Sensing
- System Architecture
- Application on X-38
- Critical Technology Developments
- Other Applications and FOS Systems
- Summary

# Introduction into Fiber Optic Sensing

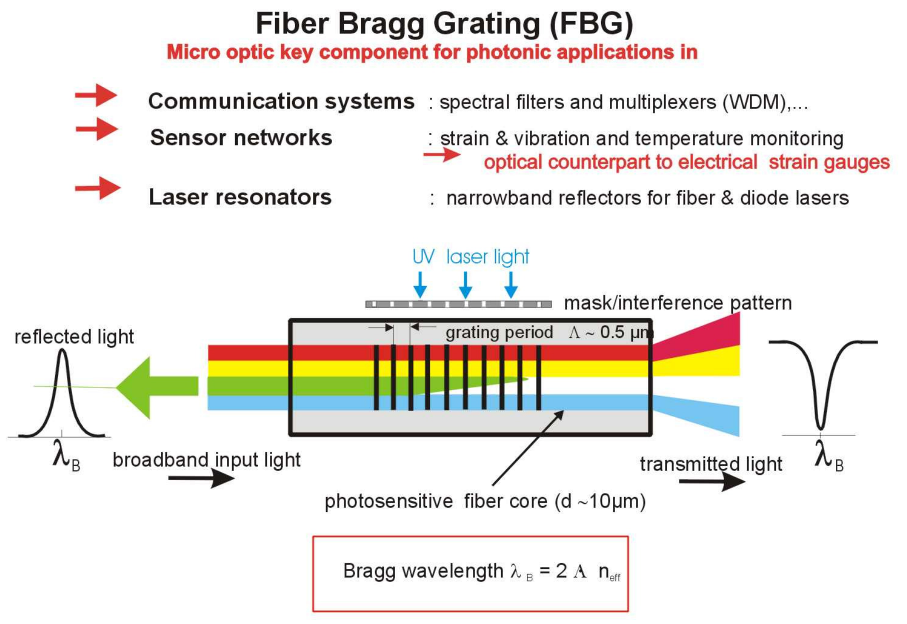
# Fiber Optic Sensing – The advantages

- Simultaneous measurement of various parameters:
  - Temperature from -260°C to 800°C
  - Strain up to 50.000 µm/m and load cylces > $10^8$
  - Concentration in gases and fluids (i.e. hydrogen)
- Insensitive to extreme environments (EMI, loads, chemical compatibility)
- Small dimensions and low system weight, i.e. signal processing unit, 100 measurands and harness < 5kg
- Feasibility of structural conform embedding into composites
- Signal processing unit and sensor fiber qualified for deployment in extreme environments

# Functional Principle




- Intrinsic distributed measurement points in an optical fiber
- Up to 20 Bragg gratings distributed along one single fiber
- Identification of single measurement points via WDM (wavelength division multiplexing)

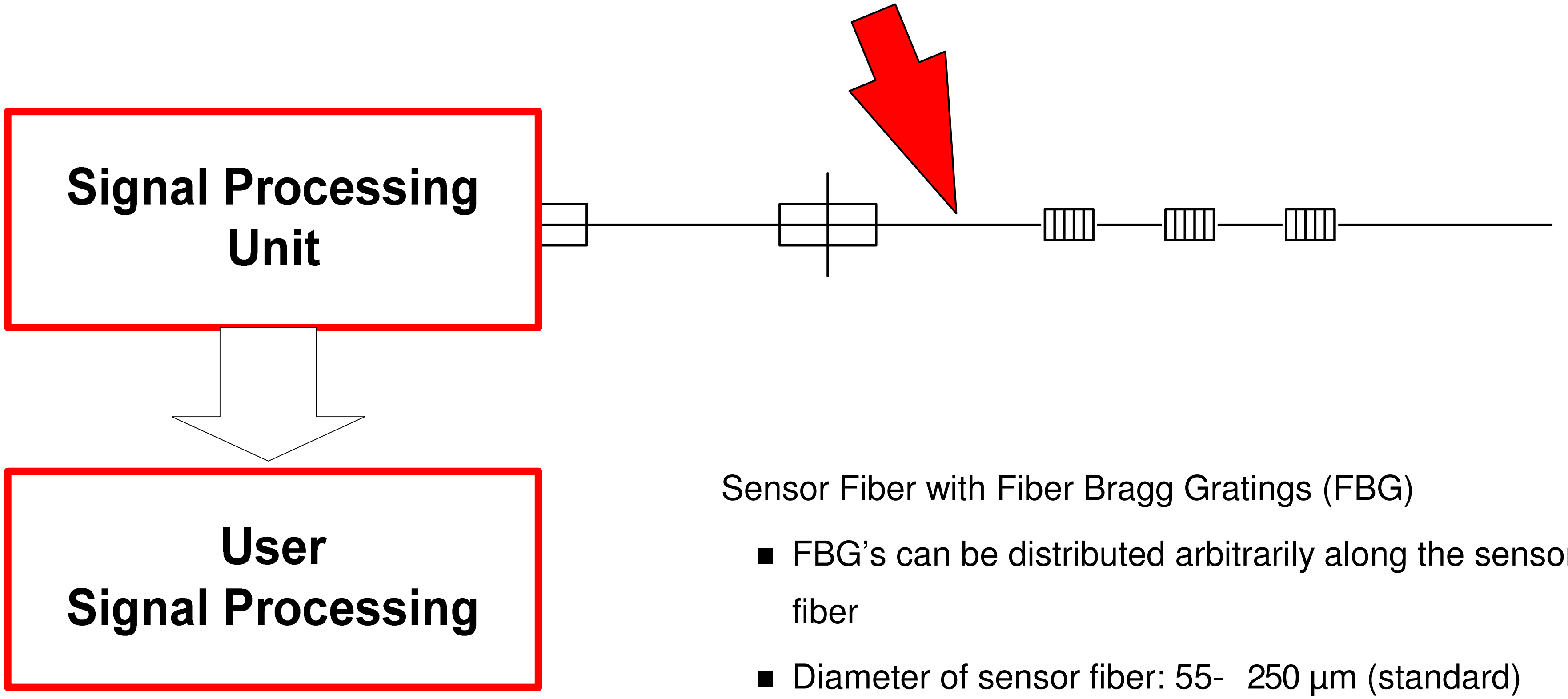



Bragg Grating

- Filtering of a small portion of light out of a broadband spectrum
- Inscription of Bragg gratings into the fiber core via a UV Laser

# System Architecture

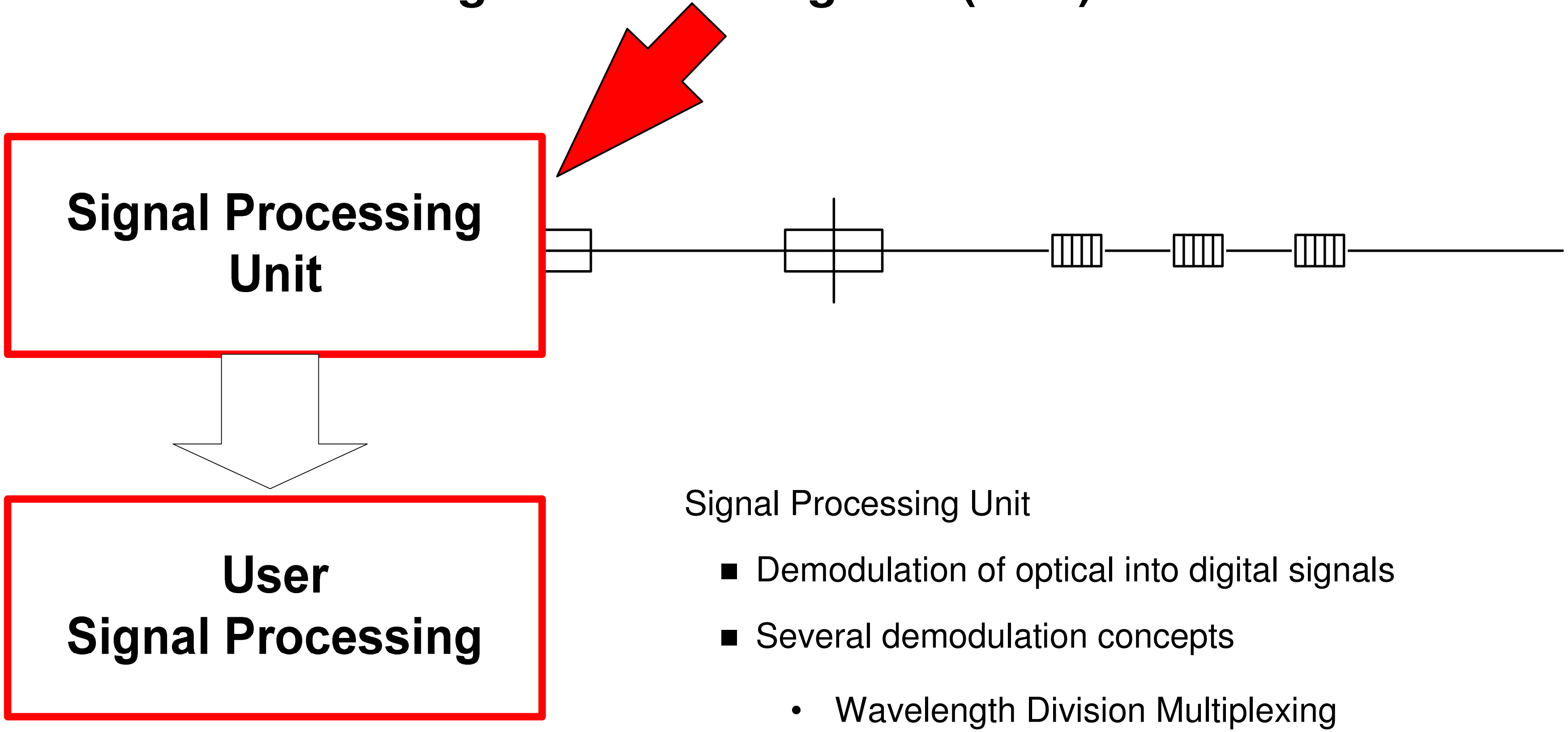
# System Architecture – Sensor Faser and Fiber Bragg Gratings




Sensor Fiber with Fiber Bragg Gratings (FBG)

- FBG's can be distributed arbitrarily along the sensor fiber
- Diameter of sensor fiber: 55- 250 µm (standard)
- Coating: Acrylate (standard), Polyimide, ORMOCER, Metallic
- Max. elongation: 1% (Standard), up to with draw tower FBG's

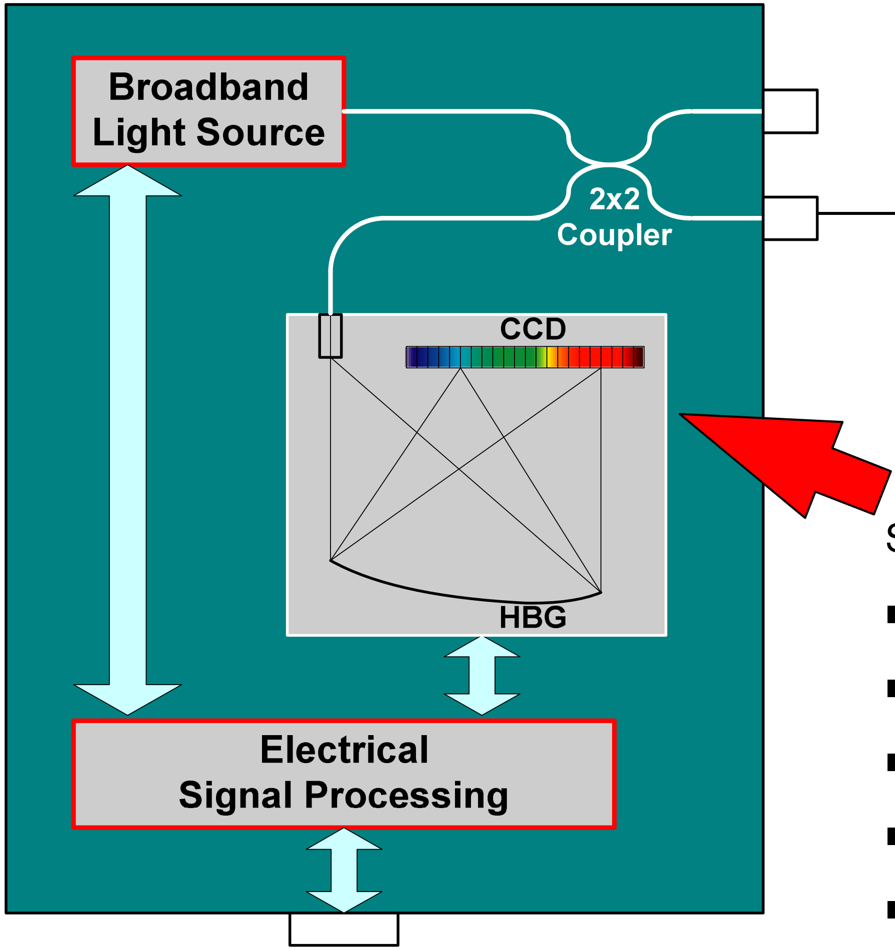
# System Architecture – Signal Processing Unit (SPU)

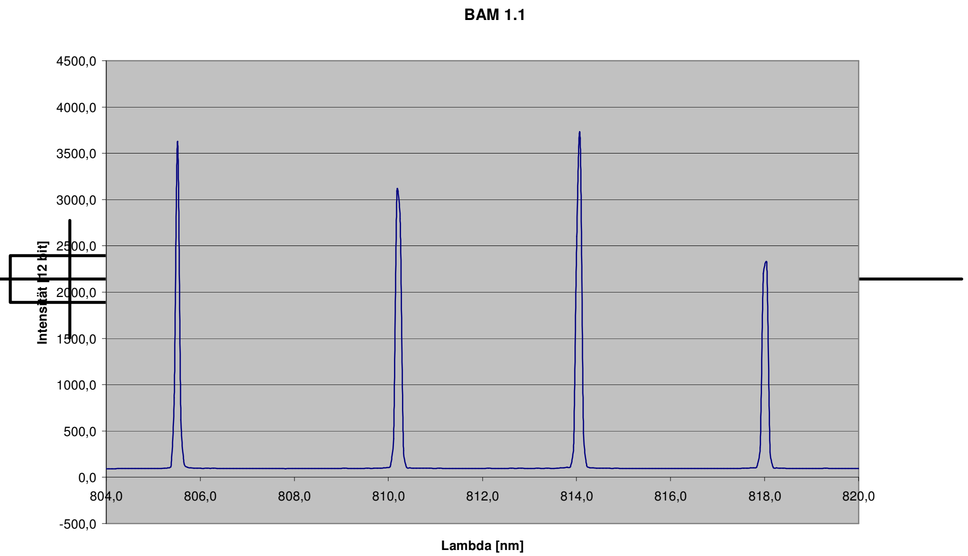



Signal Processing Unit

- Demodulation of optical into digital signals
- Several demodulation concepts
  - Wavelength Division Multiplexing
  - Time Division Multiplexing

# Signal Processing Unit (SPU)




Spectroscopic demodulation:

- CCD line sensor in the 800nm range
- Synchronous data sampling (photo shot)
- High sensitivity, resolution and SNR
- Mechanical stable and reliable
- Verified measurement technique

# Fiber Optic Signal Processing Under Severe Environmental Conditions

## 800 nm Wavelenght Range instead of 1500 nm

- Usage of inexpensive silicon based photodetectors
- Relaxed detector cooling
- Feasibility of small, robust and inexpensive spectrometers (industrial standard)
- Availability of double measurement range (800 nm range Dl / De = 7 pm / 10 µm/m, in the 1500 nm range Dl/De = 15 pm / 10 µm/m)
- Good resolution for strain and temperature monitoring (resolution < 3pm or <5 µm/m respectively)
- High MTBF (45.000 h for X-38)

## Spectrometer Design

- Synchronous data sampling (photo shot) of all FBG's (→ Very important for dynamic load monitoring)
- High speed detectors available
- Secure availability of all components in MIL standard (i.e. light source from fiberoptic gyros)

# Application on X-38

# Application on X-38

Objective

- Demonstration of Health Monitoring Technologies on-board of the NASA re-entry vehicle X-38

Project TETRA (Technologies for Future Space Transportation):

- Cooperation between DLR and NASA on RLV technologies
- Period: 1996 -2002
- Funded by BMBF, Bavarian State and own funds

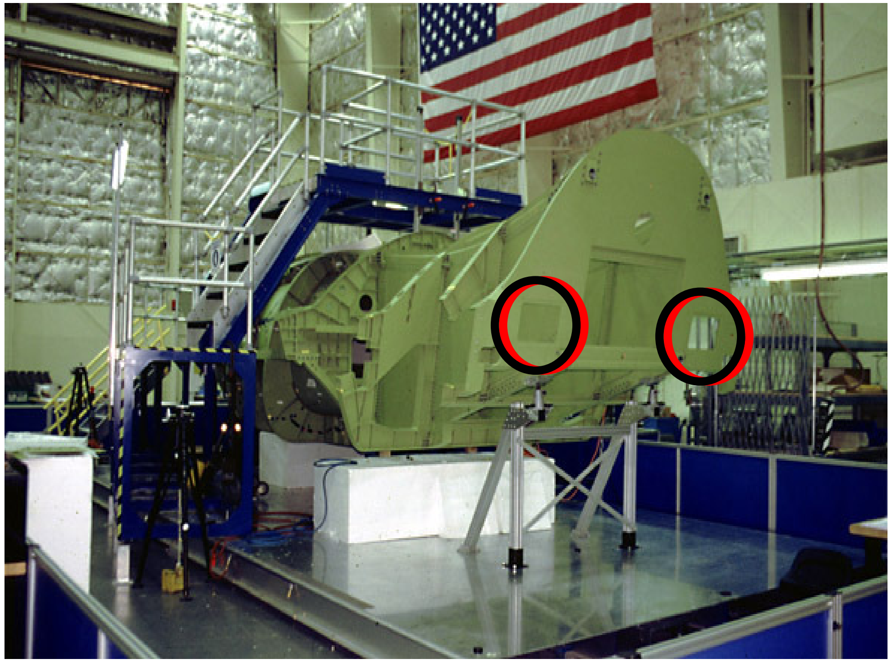
Fiber optic sensor application

- Strain and temperature measurements
- Sensing of strain and temperature measurements during ascent and decent

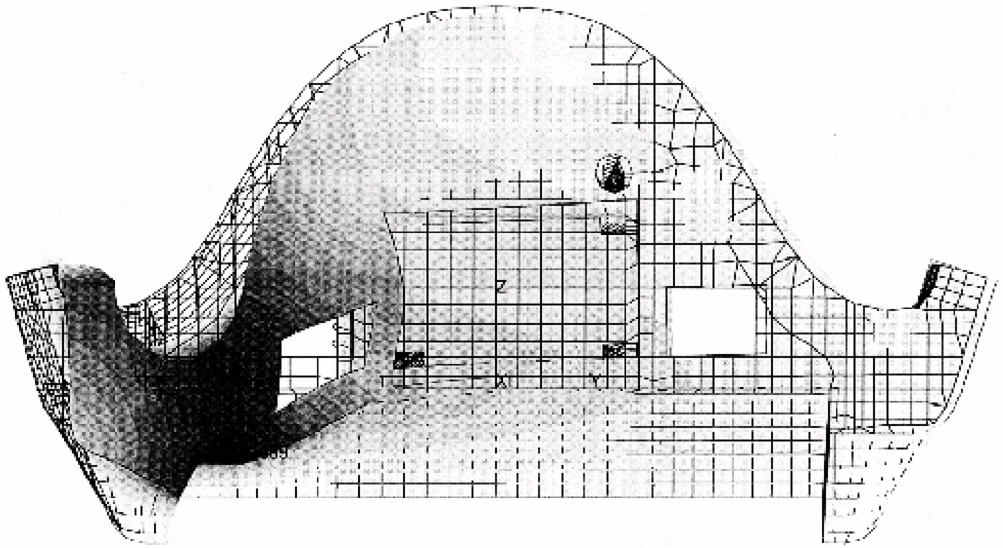

Dryden Flight Research Center ED97-43903
X-38: Crew Return Vehicle technology demonstrator re-entering Earth's atmosphere. 1997 Artist concept for NASA

# Application on X-38

| | |
|---|---|
| Strain range: | -1000 µm/m – 4000 µm/m |
| Temperature range | -40°C - 180°C |
| Sample rate | 1 Hz (static values) |



Load Measurements on the aft structure of the X-38



# X-38 Requirements for the SPU

Environmental vibration

- 20Hz 0.01g$^2$/Hz
- 40Hz 0.160g$^2$/Hz
- 350Hz 0.160g$^2$/Hz
- 2000Hz 0.0005g$^2$/Hz
- Overall 9.87grms

Thermal-vacuum

- –15°C to 50°C
- pressure from 0 bar to 1 bar

Supply Power Voltage: 28 VDC ±6 VDC

(Continuous and inrush resistant power supply)

EMC/EMI: SPP 30237

Data: RS 422

# Critical Technology Developments

Signal Processing

Sensor Fiber

Verification

# Critical Technology Developments – Signal Processing Unit

X-38 requirements

- Operation during severe environmental conditions
- Compact and rugged design for space application
- Low power consumption
- Qualified components

Compensation of environmental impact on sensing

- Vaccum
- Temperature range
- Vibration

# Environmental Impact on Sensing

## Vaccum

Effect

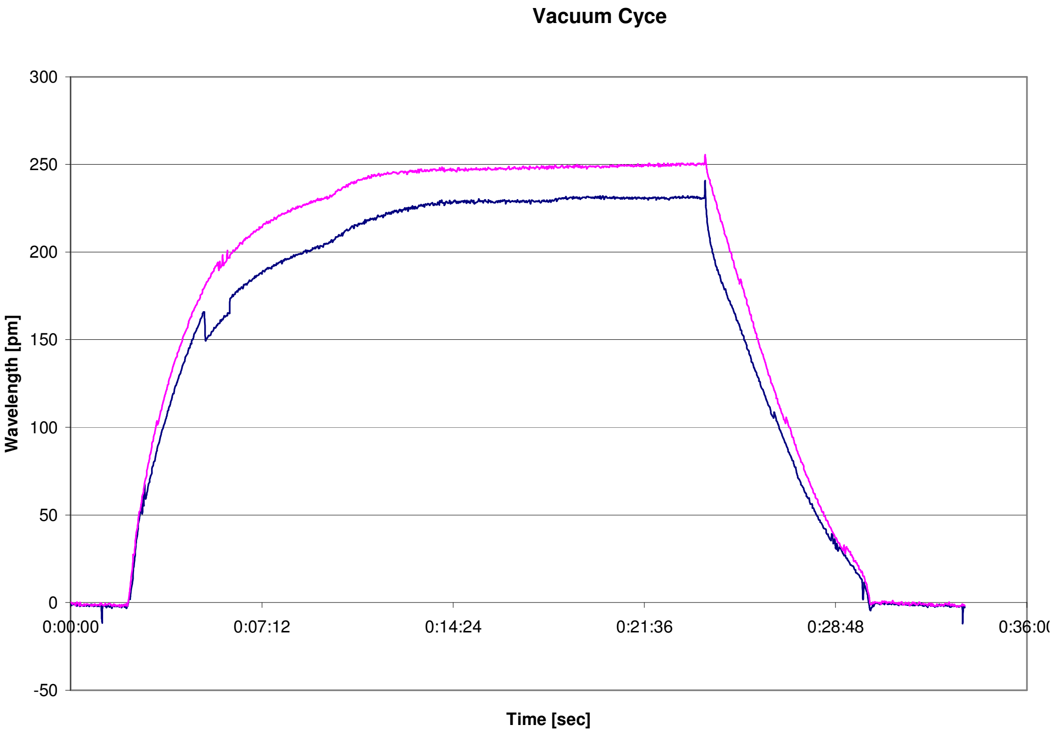
- Drift with pressure changes

Reason

- Caused by the refractive index changes between normal pressure and vacuum.

Technical Solution

- Reference grating



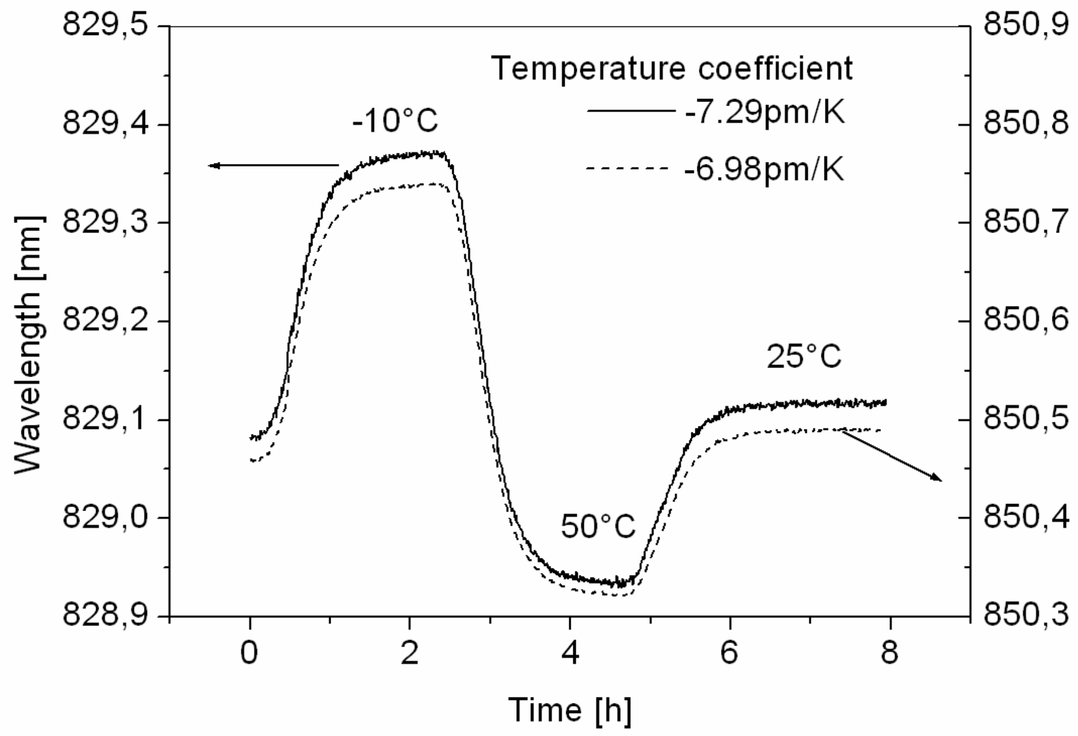
# Environmental Impact on Sensing

## Temperature

Effect
- Thermal drift of spectrometer

Reason
- Extension of optical path
- Thermal drift of spectrometer grating

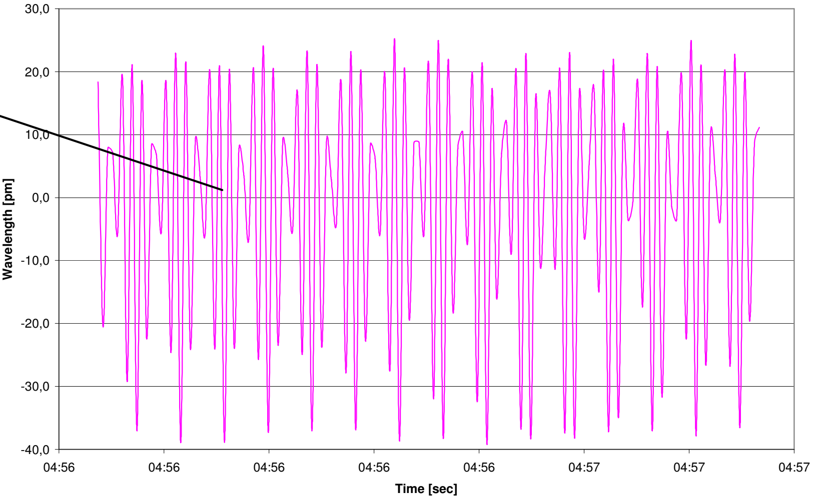
Technical solution
- Optical bench with minimal CTE (e.g. Invar
- Reference grating



# Environmental Impact on Sensing

## Vibration

w/o reference grating




Effect

- High noise due to disturbances on optical path

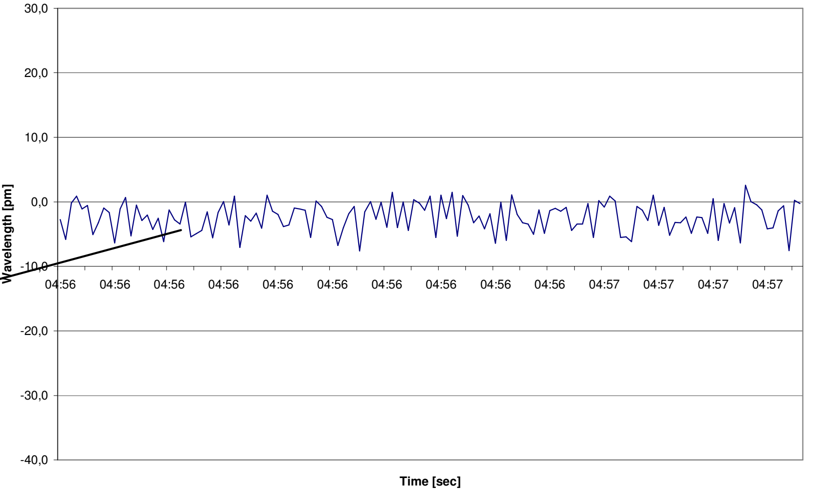
Reasons

- Vibration of optical bench
- Vibration of connectors

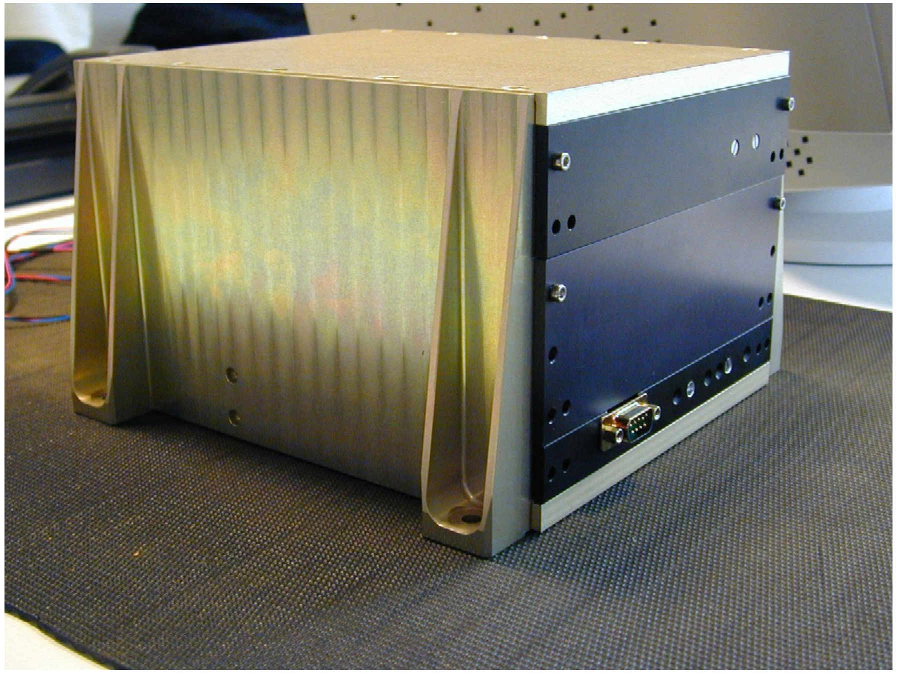
Technical solution

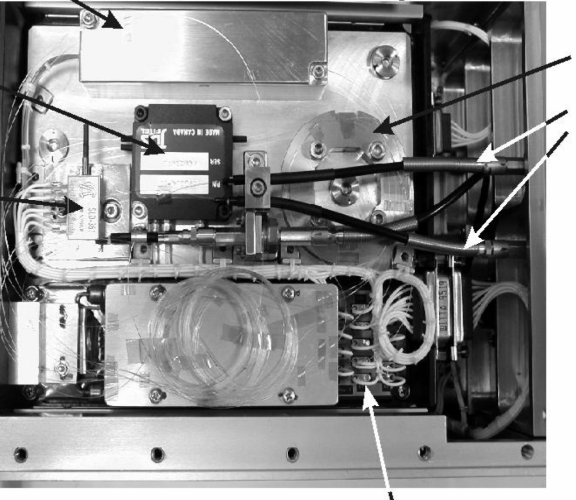
- Reference grating

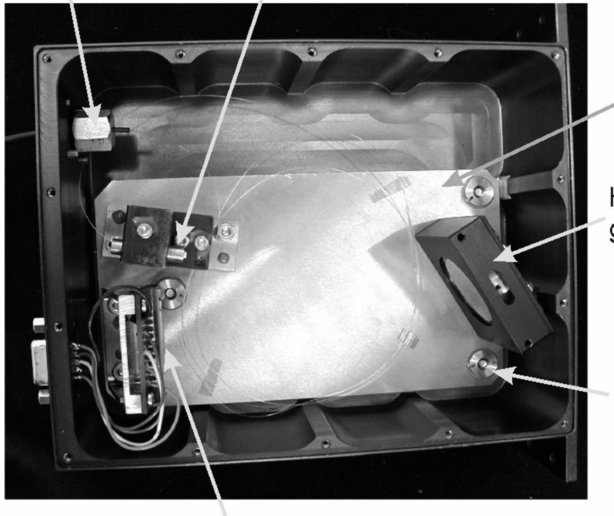
With reference grating



# SPU Design



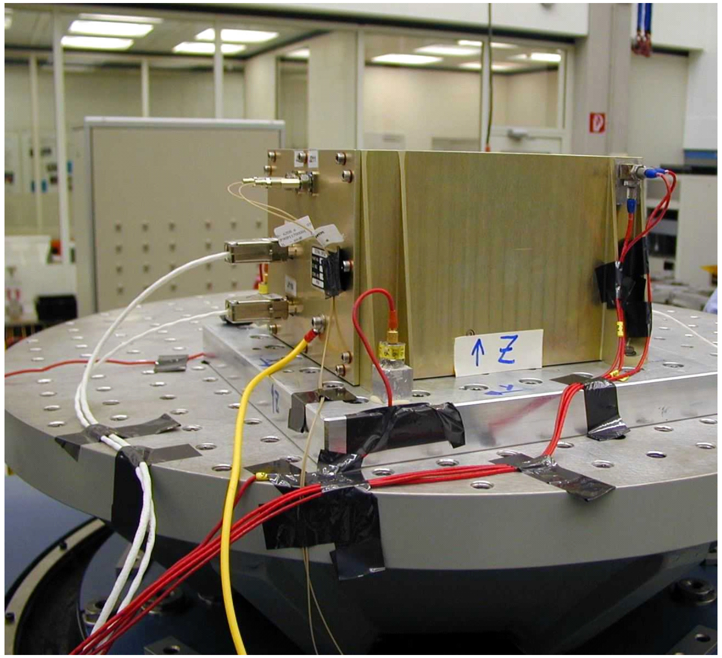


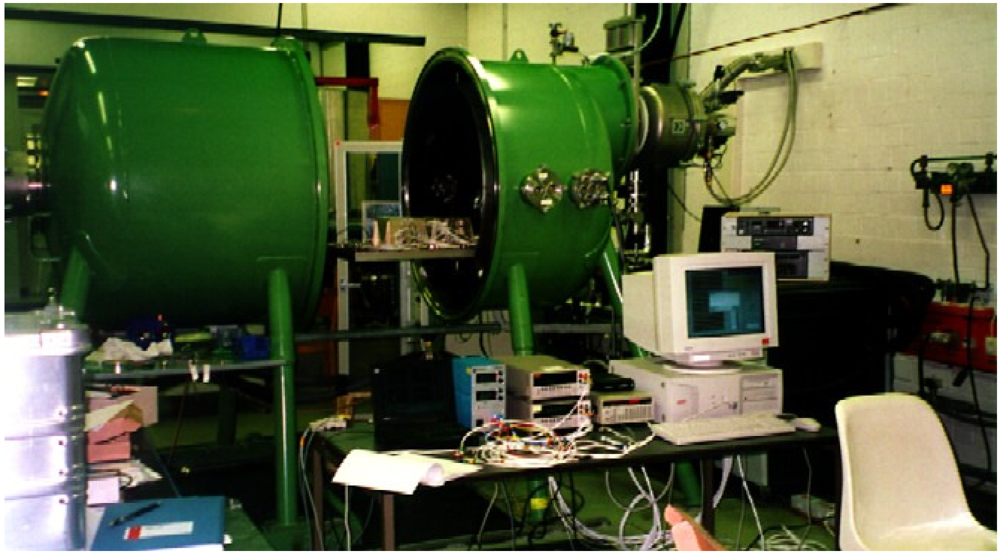

Dim: 220 x 220 x 140 mm

Mass: 5,5 kg

# SPU Verification




Vibration test



Thermal vacuum tests

# Critical Technology Developments - Sensor Fiber

X-38 requirements

- Gluing on aluminium
- Severe environment

General sensor fiber requirements

- Suitable coating for application
- Characteristica of sensor fiber
  - Quality problems with recoated sensor fibers
  - No standards for characteristic values (e.g. $p_{eff}$, mechanical and thermal hysteresis, etc.)

# Critical Technology Development - Gluing

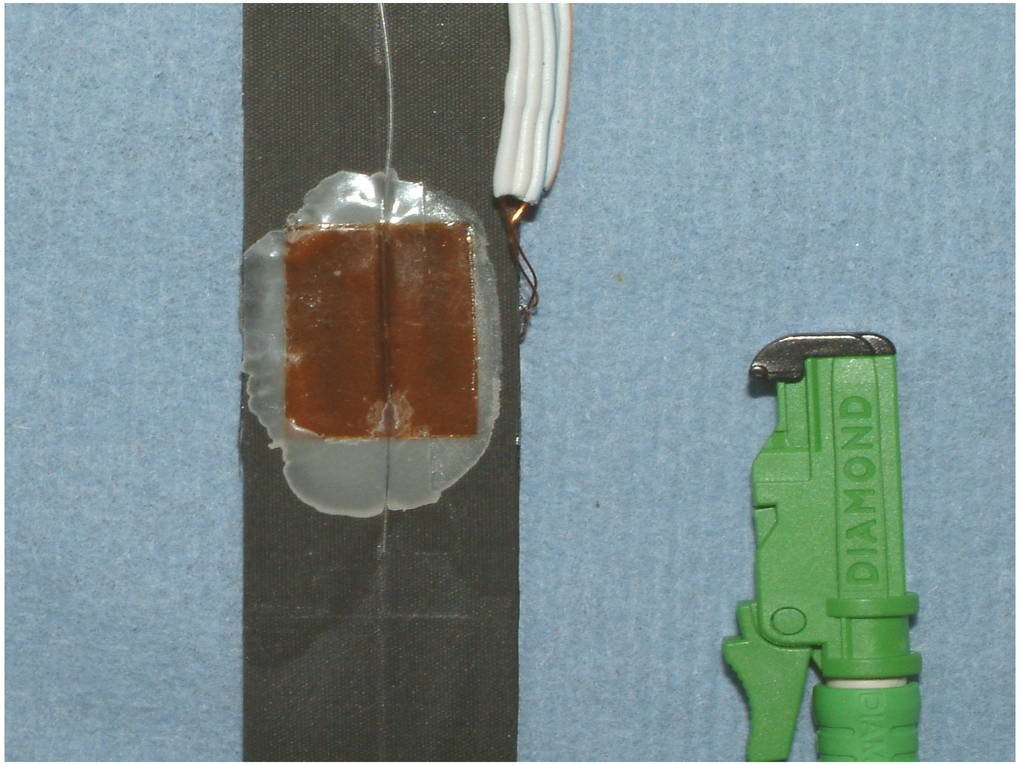
Problem

- Many criterias to be considered: coating, sample material, surface characteristica, environmental conditions
- Low  mechanical transfer behaviour of coatings
- Low reproducibility

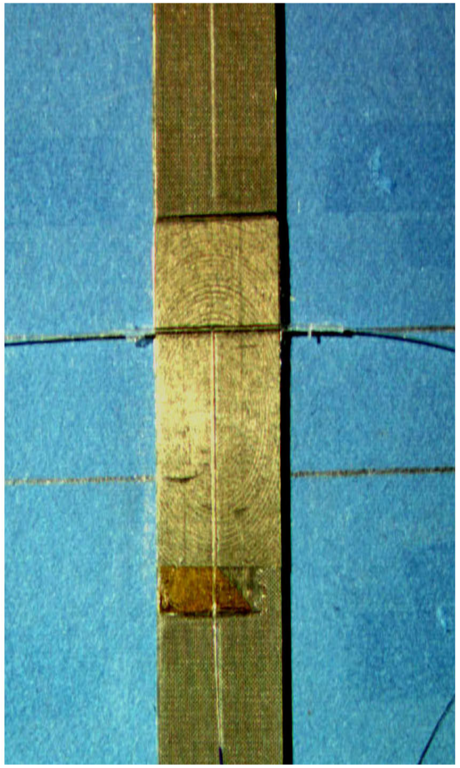
Solution

- Excecution of a glue trade off
- Design of different sensor configurations, e.g. sensor pads
- Development of an application procedure inclusive tools
- Qualification tests with each FBG before gluing
- Calibration required for each sensor after gluing

# Critical Technology Development - Gluing



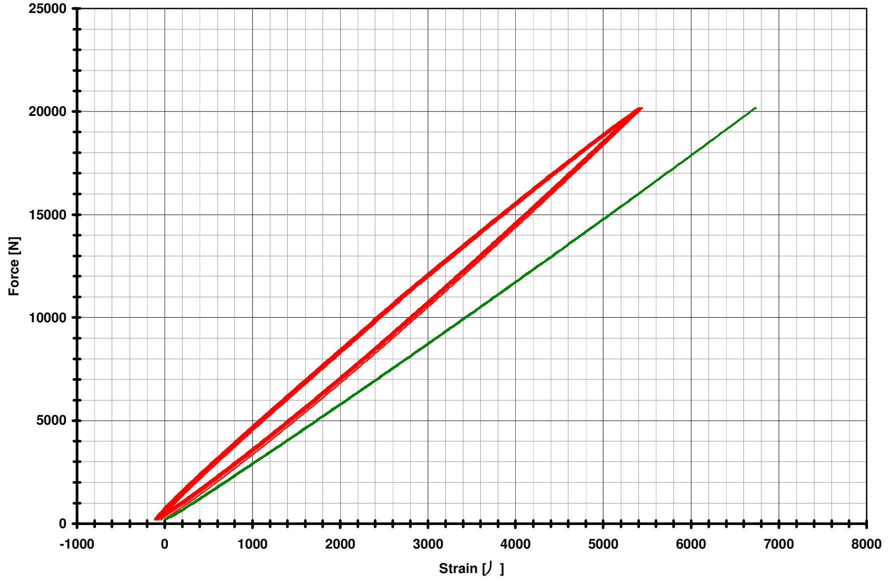

Fiber glued with sensor pad



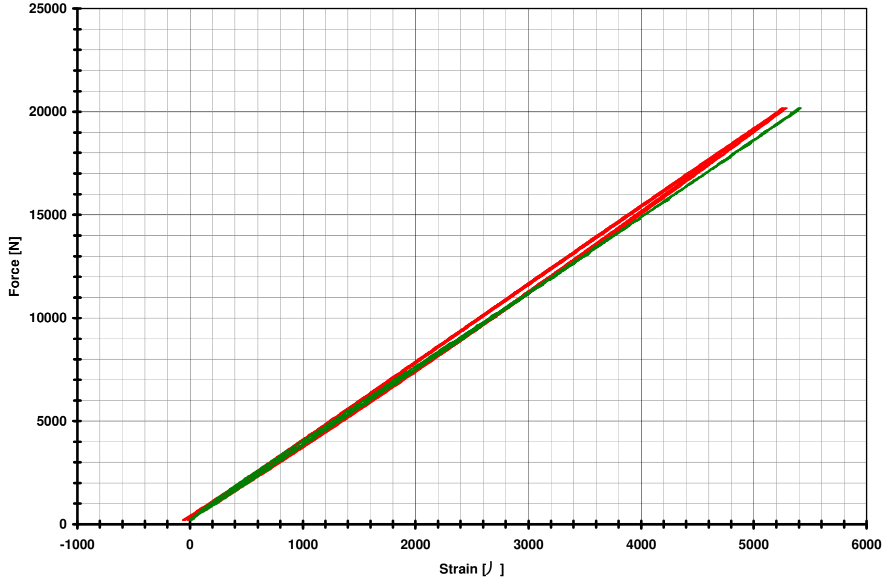
Sensor fiber glued directly

# Critical Technology Development - Gluing

## Bad connection




## Good connection



# Critical Technology Development - Coatings

Acrylate (standard)

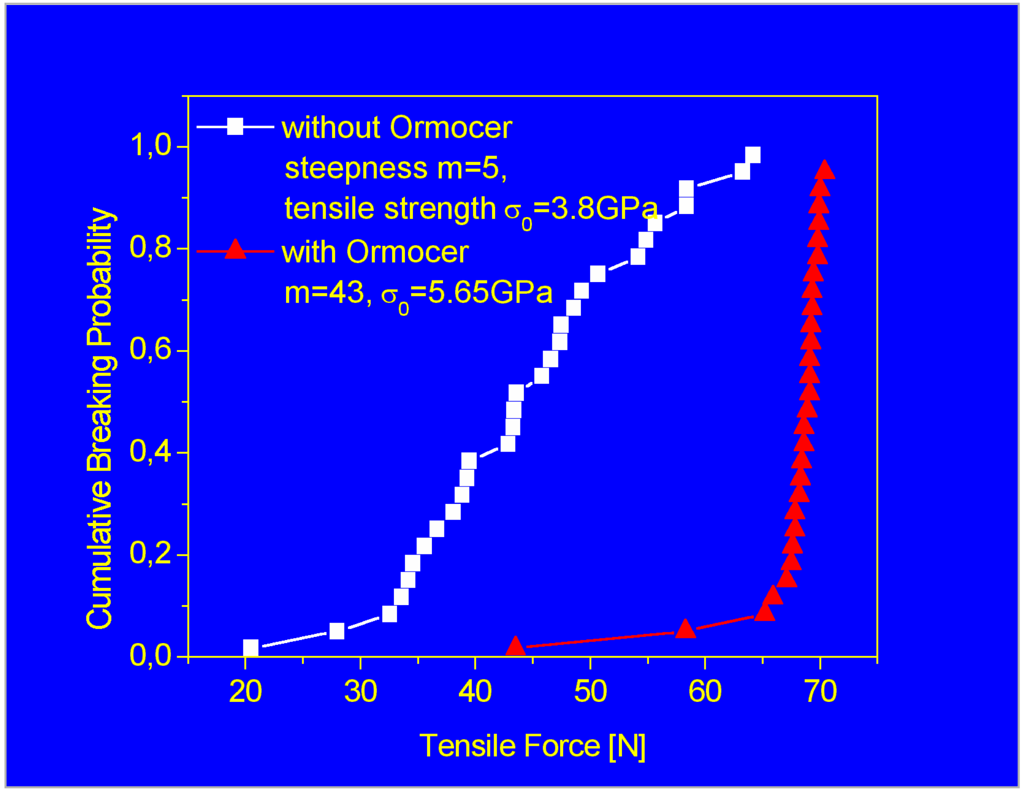
- Low mechanical and thermal stability

Polyimide

- Thermal stability –270...+280℃
- Improved mechanical strenght

ORMOCER® (Organic Modified Ceramics)

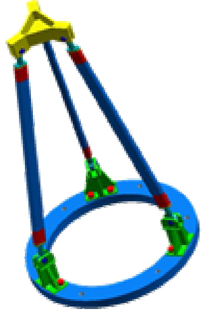
- High mechanical stability
- Thermal stability –60...+250℃




**Weibull diagram: mechanical breaking probability of Polyimide coated fibres with and without ORMOCER re-coating (thickness 20µm)**

# Other Applications and FOS Systems

# FOS Experience of KT - Overview



**TETRA**
Machbarkeit für Raumfahrt-anwendungen

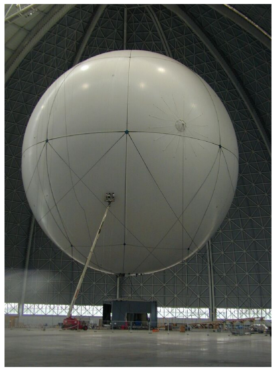
**AFOS**
Optimierung der Technologie

**FOS Produkt**
Anspruchsvolle Testsysteme

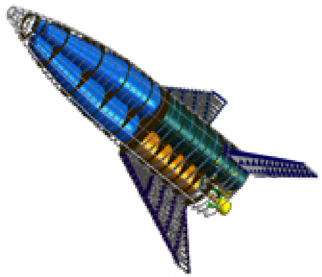
**FOS Produkt**

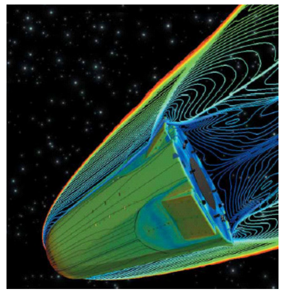
**GTMS**
Regelung von Luftschiffen

**Multi-FOS**
Erweiterung der Leistungsfähigkeit



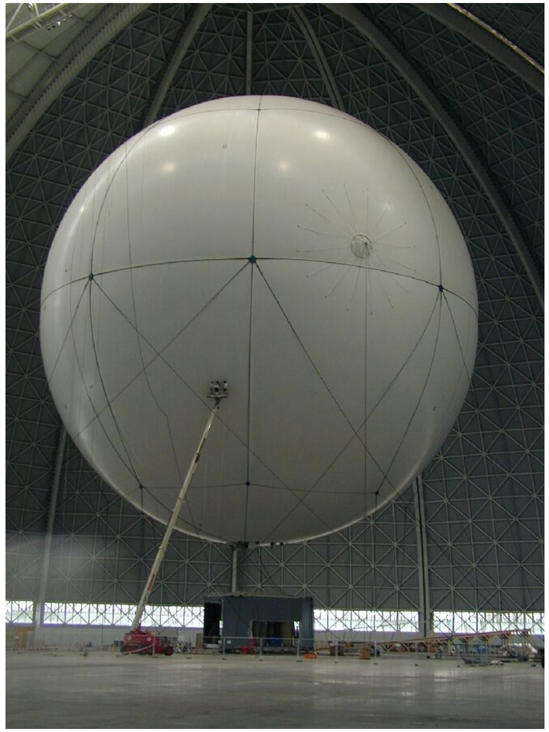
Entwicklungsstufen





# Industrial Applications

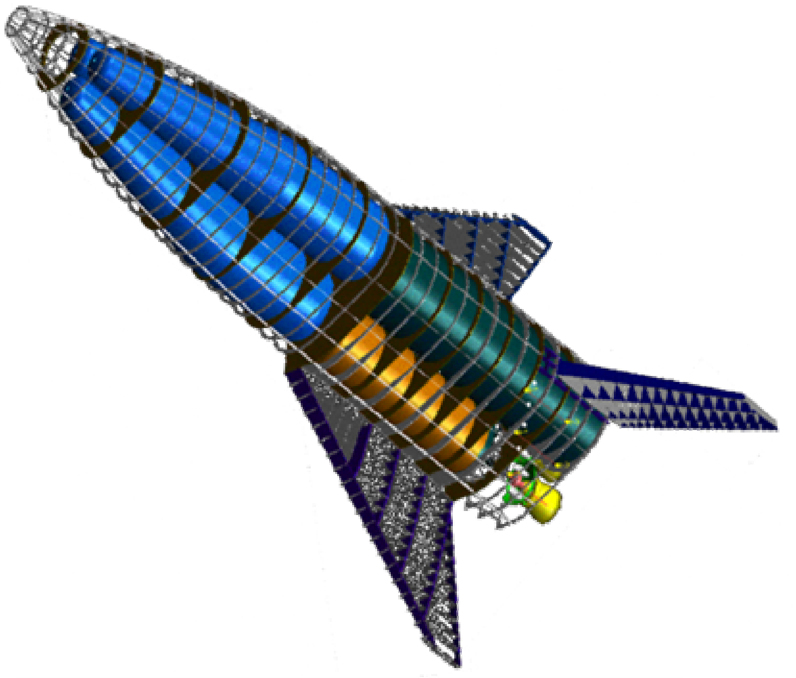
- Aviation (health monitoring)
- Airships (flight control)
- Wind turbine (process control
- Automotive (load monitoring)

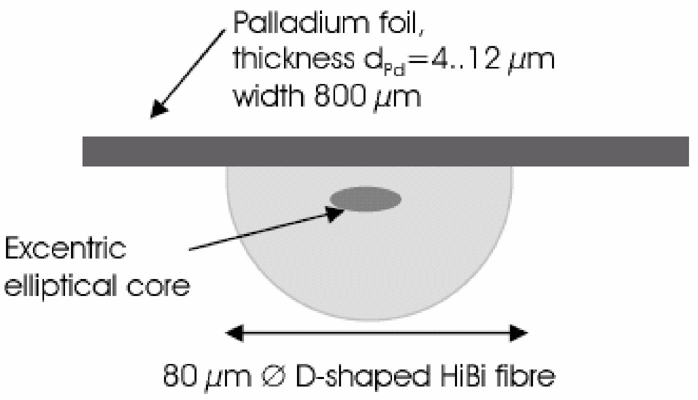



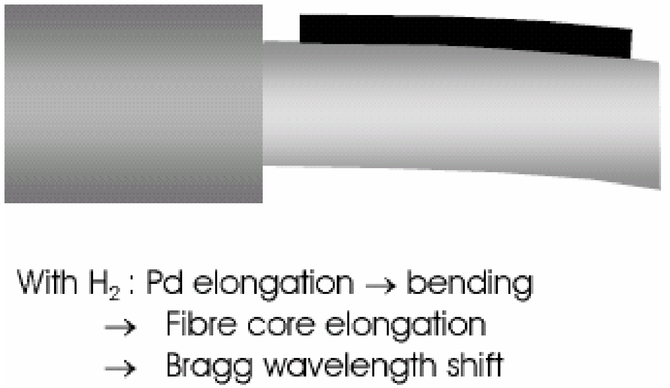
# Space Application

Multipurpose Fiber Optic Sensor for RLV

- ESTEC TRP contract
- Monitoring of strain, temperature and hydrogen concentration in cryogenic hydrogen tanks
- Sensor embedded in composite

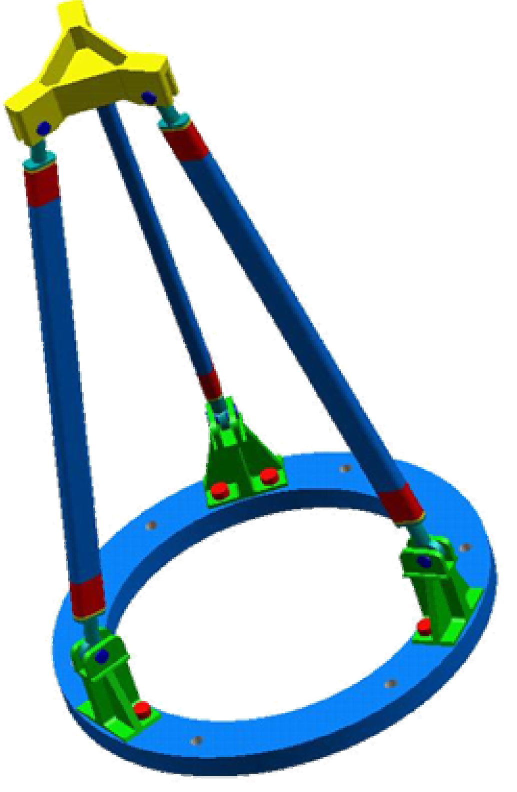




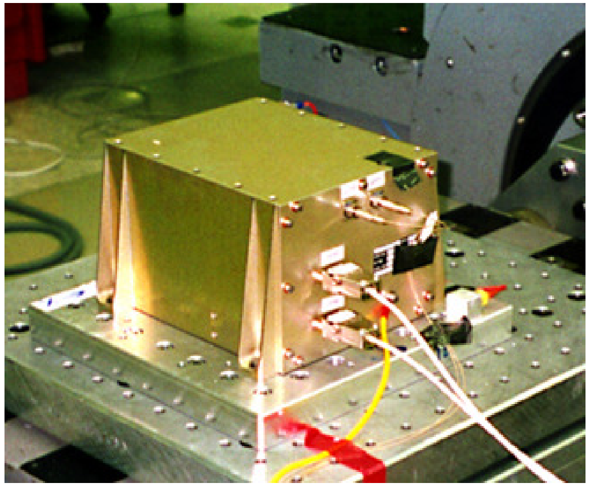
# Space Application

Structural Deformation Control of high precision optical bench (ESTEC contract)

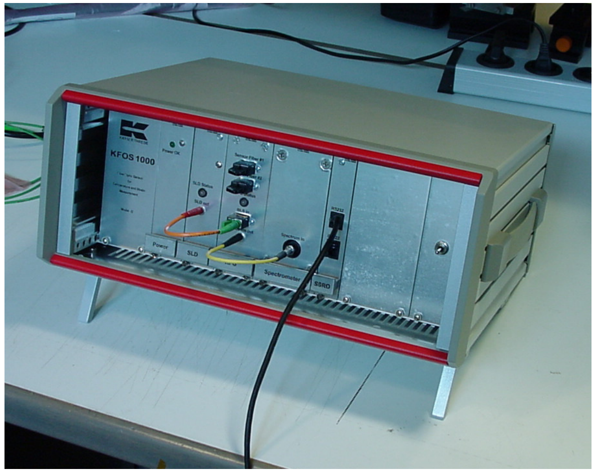



**Cassegrain tripod**

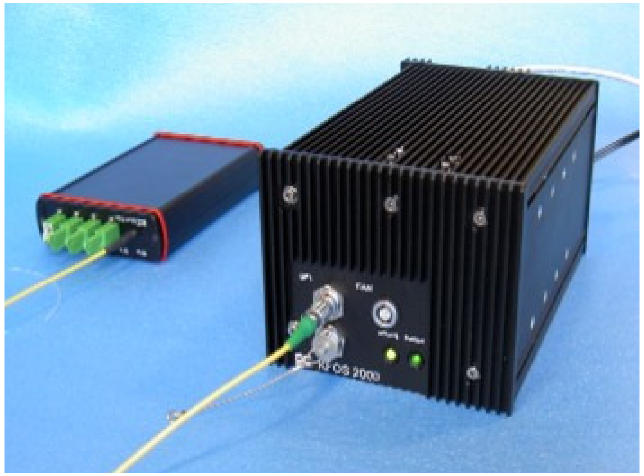
# Signal Processing Units For Different Applications



Space




Laboratory / industry




High-end test system, e.g. for Automotive

# Conclusion

- Robust and compact signal processing unit suitable for almost all environments
- High mechanical strength and lifetime of sensor fibers
- Compensation of environmental impact on signal
- High Reliability and availability due to design and selection of components (high MTBF, remote monitoring, Built-In-Test)
- Easy to adapt to application requirements (interfaces, data format, signal processing