The Fiber Optic Sensor Group

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Consortium CERICT

And

Optosmart Ltd

Thanking you very much for a nice return to high energy physics world after 25 years

CeRICT

CRdC Tecnologie Scarl

opto smart

CERN

Università degli Studi del Sannio

DiT

Achromatic storage ring for free-electron lasers

Antonello Cutolo[a] and John M. J. Madey
Stanford Photon Research Laboratory, Stanford University, Stanford, California 94305

(Received 8 April 1987; accepted for publication 7 July 1987)

We discuss the possibility of taking advantage on achromatic magnetic mirrors (α magnets) to construct a storage ring for free-electron lasers, where the electron trajectories are energy independent in the straight sections. This property might be efficiently used to noticeably reduce the momentum compaction.

I. INTRODUCTION

Free-electron lasers (FEL's) require high-quality electron beams with a small emittance, low-energy spread, and high peak current. On the basis of the experience gained in the construction of the first-generation devices, it seems that storage rings might be the best candidate to provide electron sources for high-efficiency free-electron lasers. This consideration has led Madey's group, at Stanford University, to start the construction of a storage ring completely devoted to FEL's with the ultimate goal of producing ultraviolet coherent radiation.

A major limit of storage ring free-electron lasers is the enhancement of the energy spread of the circulating e bunch because of its multiple interaction with the intracavity radiation.[1,2] This effect, together with the chromatic properties of the actual storage rings, increases the transverse dimensions of the e bunch with a consequent decrease of the peak current. In order to get rid of these problems, Madey proposed a transverse gradient FEL.[3] Later Kroll[4] showed that, in these devices, a greater energy acceptance is accompanied by an emittance increase. On this line of argument we can state that, in an ideal storage ring, the electron trajectories should be energy independent (zero-momentum compaction).

Therefore, in this paper, we discuss the possibility of using an achromatic storage ring for free-electron laser applications. The basic idea is the use of achromatic magnetic mirrors, better known as α magnets.[5-7]

II. ACHROMATIC STORAGE RING

With reference to Fig. 1, an α magnet basically consists of a magnetic field distribution given by

$$B_x = B_y = 0\,,$$
$$B_z = \begin{cases} 0, & \text{for } x < 0, \\ Gx^n, & \text{for } x > 0, \end{cases} \qquad (1)$$

G and n being constants. A charged particle incident on the input plane of this magnet ($x = 0$) with an angle α (see Fig. 1) will be reflected in the specular direction in a way completely independent of its energy. As we shall see, the only energy-dependent parameter is the time spent by the particle, inside the α magnet, to be completely reflected. A little more detailed analysis requires the equations of the motion of a charged particle (with charge e, mass m, and normalized energy γ) in the static magnetic field, described by Eqs. (1):

$$\frac{d^2x}{dt^2} = \frac{g}{\gamma}x^n\frac{dy}{dt}\,,$$
$$\frac{d^2y}{dt^2} = -\frac{g}{\gamma}x^n\frac{dx}{dt}\,, \qquad (2)$$

where $g = Ge/m$. Equation (2) can be easily cast in the form

$$\frac{dy}{dx} = \frac{\beta c\sin\alpha - gx^{n+1}/(n+1)\gamma}{\sqrt{\beta^2c^2 - [\beta c\sin\alpha - g/(n+1)\gamma]^2}}\,, \qquad (3)$$

where $\beta = V/c = (1 - 1/\gamma^2)^{1/2}$ is the normalized velocity of the electron on the input plane of the α magnet. Exact solutions of Eq. (3) can be obtained only numerically. On the other hand, it is very easy from Eqs. (2) and (3) to calculate the quantities x_1 and x_M (see Fig. 1) and the time t_α spent by the particle to cover the complete trajectory inside the α magnet:

$$x_1 = \left(\frac{(n+1)\beta c\gamma\sin\alpha}{g}\right)^{1/(n+1)}\,,$$
$$x_M = \left(\frac{(n+1)\beta c\gamma(1+\sin\alpha)}{g}\right)^{1/(n+1)}\,,$$
$$t_\alpha = 2\int_0^{x_M}\frac{dx}{V_x}$$
$$= \frac{2x_M}{\beta c}\int_0^1\frac{d\xi}{\sqrt{1 - \left(\sin\xi - \frac{g\xi^{n+1}}{\gamma c^2\beta^2(n+1)}\right)^2}}\,. \qquad (4)$$

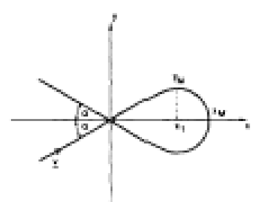


FIG. 1. Schematic of an α magnet, for which the magnetic field distribution is described by Eqs. (1). α is the injection angle. We note that, for $n = 1$, the α magnet reduces to half a quadrupole.

[a] Permanent address: C.I.E.Q.P., Dip. Ingegneria Elettronica, Via Claudio 21, 80125 Napoli, Italy.

SMART SENSORS

PROCESS MONITORING

CURE MONITORING,
GLASS TRANSITION
TEMPERATURE
DETECTION,
RELAXATION
MONITORING.
PHASE TRANSITION
IDENTIFICATION

MULTIFUNCTION SENSING SYSTEM

STRUCTURAL HEALTH MONITORING

STATIC STRAIN
MAPPING,
TEMPERATURE
DISTRIBUTION,
DYNAMIC STRAIN
MEASUREMENTS

High quality

Advanced materials

Cost reduction

Smart Processing

Safety Improvement

Maintenance cost reduction

Crack detection

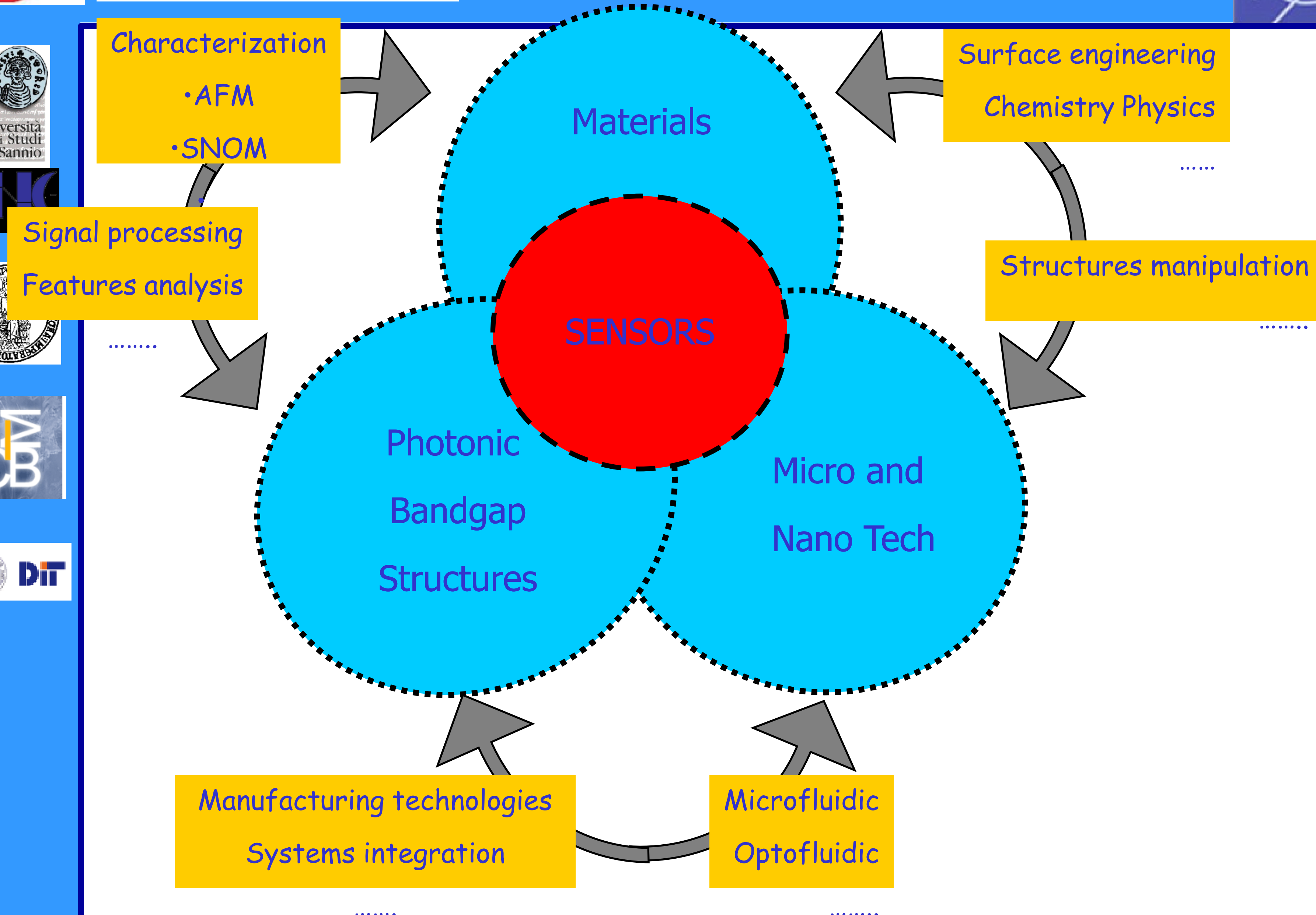
Damage identification

NEEDS CeR ICT

CRdC Tecnologie Scarl

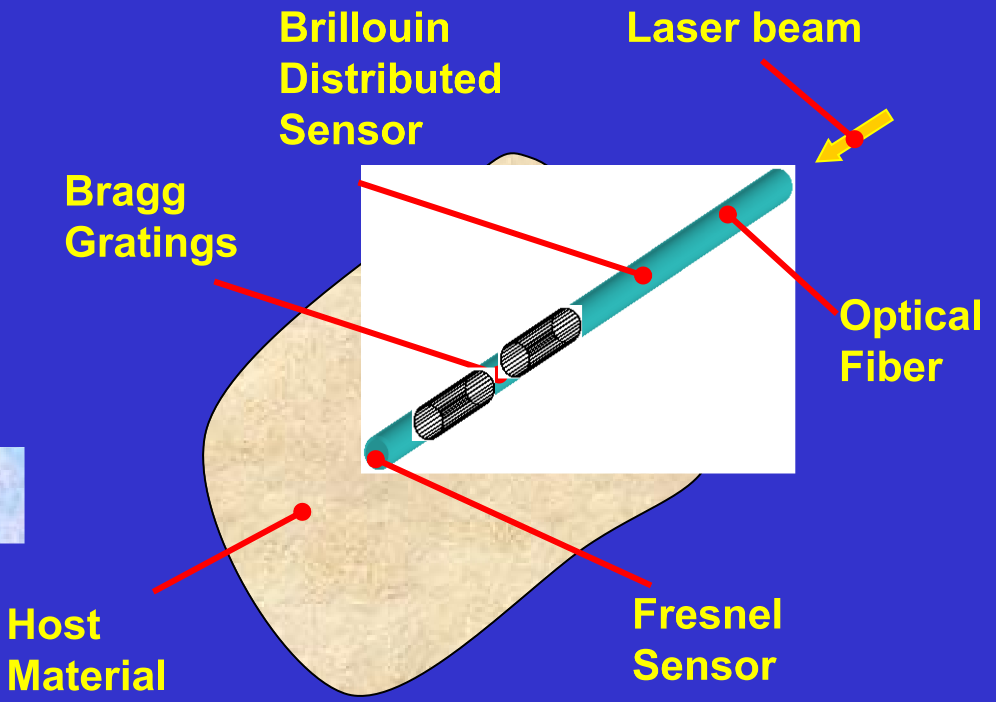
optosmart

CERN



The Basic "IDEA"

- Multifunctionality
- Localized and Distributed
- Integrated

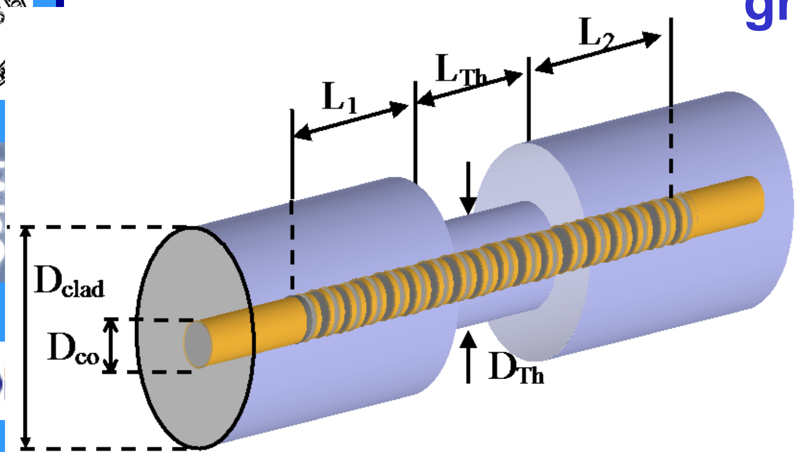


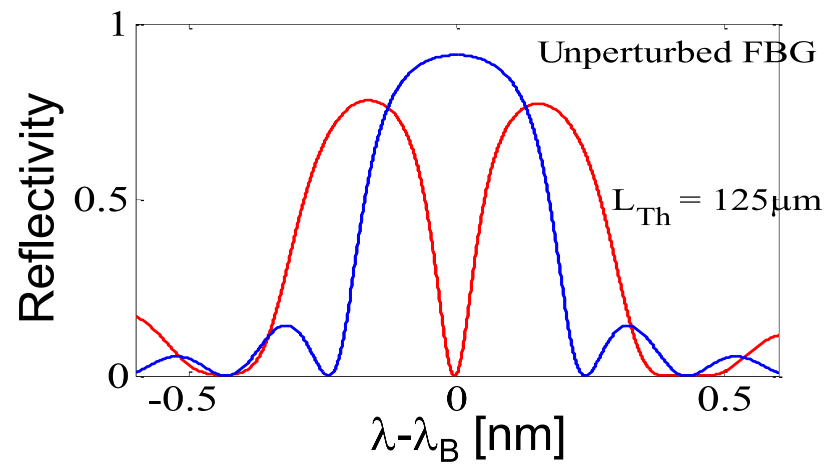
INNOVATIVE TOOLS FOR APPROPRIATE FUNCTIONALIZATIONS

- **NOVEL INTERROGATION SCHEMES** (very small, compact and with a bandwidth of several MHz)
- **INTEGRATION WITH OTHER MATERIALS** (Polymers, Metal Oxides, Carbon Nanotubes)
- **BANDGAP ENGINEERING** (microstructured FBG besides the actual uniform and chirped)
- **INTEGRATION WITH TLC OPTICAL NETWORKS**

Micro-Structured FBGs (patent filed)

The micro-structured FBG consists in a standard gratings with the cladding layer removed on a small and well-defined region along the grating.

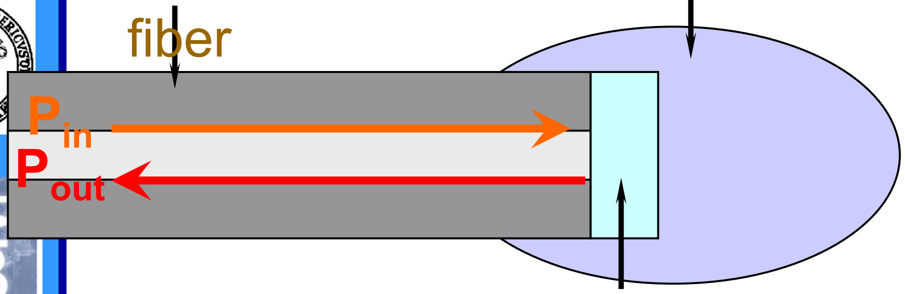




The main effects of the localized perturbation of the periodic structure are:

- **the increasing of the stop-band**
- **the formation on a narrow allowed band, or defect state, inside the grating stop-band.**

Silica Optical Fiber Sensors



$$P_{out}=k \cdot R_{Film} \cdot P_{in}$$

- k is a constant
- R_{Film} is the film reflectance

$$\Delta R_{film}=f\,(\Delta\varepsilon_{Film}\,,\,\Delta d_{Film}\,,\,\Delta\varepsilon_{ext})$$

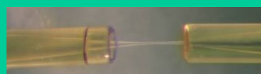
- ε_{Film} is the complex dielectric constant of the film
- d_{Film} is the film thickness
- ε_{ext} is the external medium dielectric constant

Any effect able to modify the optical and geometrical properties of the film induces changes in the film reflectance and thus in the output power recovered from the fiber

An Integrated Multidisciplinary Approach for Advanced Multifunction Photonic Sensing Systems

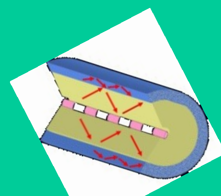
A.Cutolo, A. Cusano, M. Pisco, M. Consales, A. Iadicicco, P. Pilla, C. Ambrosino,
G. Breglio, D. Paladino, A. Crescitelli, A. Ricciardi, S.Campopiano, M. Giordano

Photonic devices

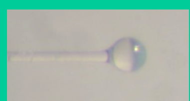


Micro-structured Fiber Gratings

Tapered Fiber



Long period Fiber Gratings



Micro resonators

Hollow core optical fiber

Integration with:

Metal oxide particle layers

Nanoporous Polymers

Carbon nanotubes

Bandgap engineering

Microstructuration

Tapering

Measured parameters:

Strain →	1 με
Temperature →	0.1 C°
Vibration →	Up to 1 MHz
Refractive index →	10^{-5}
Chemical detection →	< 1 ppm
Humidity →	< 1%
Electric and Magnetic field	

Application to:

Structural health monitoring

Damage detection

Aeronautic monitoring

Geodetical monitoring

Enviromental monitoring

Acoustic monitoring

Railways monitoring

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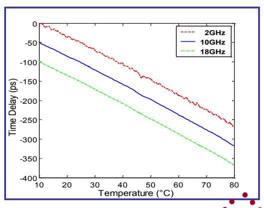
Università degli Studi del Sannio
DIT

Microwave photonics

Electrically tuned optical delay lines

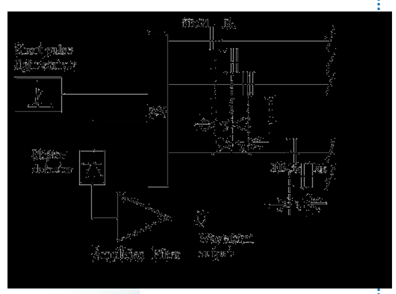
Phased array antennas

Patent filed



Time Delay Resolution 1 ps

Waveform generation of GHz signals



ST
ALCATEL

Magnetic and Electric field sensing

Vibration detection

Aeronautic field

Structural health management (0–10) kHz

CIRA

Railway applications

Track health management (0–10 kHz)

AnsaldoSTS

Patent pending

Marine applications

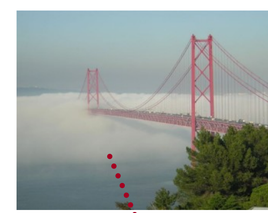
Underwater acoustic wave detection (<100) kHz

Patent pending

WHITEHEAD ALENIA Sistemi Subacquei
a Finmeccanica Company

Civil health monitoring

Static low frequency (0–100) Hz



Patent pending

D'APPOLONIA

MICRO AND NANOPHOTONICS FOR CHEMICAL SENSING

APPLICATION TO :

Air Pollution Monitoring

VAPORS (VOCs)

Limit of Detection: <0.5 ppm

GAS (NO_2)

Limit of Detection:

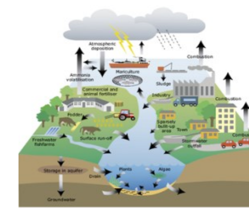
0.1 ppm

H_2 Detection at -160 °C

CRYOGENIC H_2

Limit of Detection: <1 %

Water Monitoring

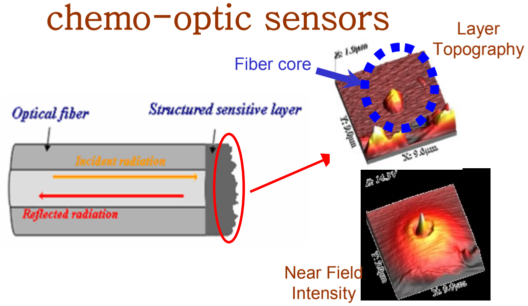


HYDROCARBONS AND AMMONIA

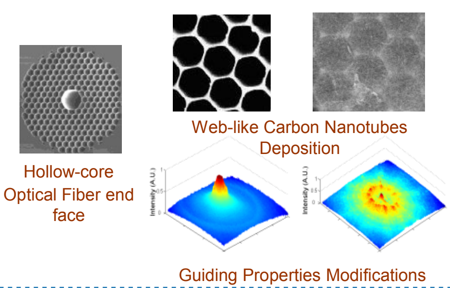
Limit of Detection: <1 ppm

ADVANCED CONFIGURATIONS :

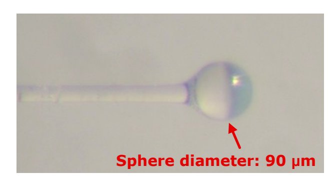
Near field chemo-optic sensors



Hollow-core Fiber filled with Carbon Nanotubes



Microlenses on tapered optical fibers



- Low cost fabrication
- Spheres diameters: 50-300 μm

MEMBERS OF THE GROUP

Public members

University of Sannio

University of Napoli

II University of Napoli

University of Parthenope

IMCB dpt of CNR

IAMC dpt of CNR

Cibernetica dpt of CNR

Stazione Zoologica Anthon Dohrn

INGV, Napoli

INFN, Napoli

Private members

Optosmart

Optoadvanced (to be founded)

CERICT Consortium

OPTOSMART ltd

Founded in 2005

Members:

Prof. Antonello Cutolo
Prof. Giovanni Breglio
Prof. Andrea Cusano
Ing. Michele Giordano

Administrator: Ing. Antonio Giordano

SOME RESEARCH PROJECTS

DILAMP, European project (CRF) 3,5 Me
MANUZEROS, European porject (CRF) 4 Me

REST , M.I.U.R. (STMicroelectronics) 6 Me
SMART, M.I.U.R. (C.I.R.A) 7,2 Me
POEMA, M.I.U.R. (Alenia WASS) 6,5 Me
SECURFERR, M.I.U.R. (Ansaldo) 8,2 Me
Public-Private Lab., M.I.U.R. (CERICT) estimated budget 25 Me

INTER-UNIVERSITY GROUP OF OPTOELECTRONICS

University of Sannio

Prof. Ing. Antonello Cutolo (Coordinator)

Prof. Ing. Andrea Cusano

Prof. Ing. Giovanni Persiano

Ing. Marco Pisco (Post Doc)

Ing. Marco Consales (Post Doc)

Ing. Domenico Paladino (Post Doc)

Ing. Alessio Crescitelli (Post Doc)

Paola Ambrosino (Project Manager)

University of Napoli "Federico II"

Prof. Ing. Giovanni Breglio

Prof. Ing. Andrea Irace

Ing. Lucio Rossi (Post Doc)

Ing. Martina De Laurentis (Post Doc)

University of Napoli "Parthenope"

Prof. Stefania Campopiano

Ing. Agostino Iadicicco (Researcher)

Ing. Armando Ricciardi (Post-Doc)

Ing. Pierluigi Foglia Manzillo (PhD student)

Institute for Composite Biomedical Materials (CNR, Napoli)

Ing. Michele Giordano (Researcher)

Ing. Pierluigi Pilla (Post-Doc)

Ing. Antonietta Buosciolo (Post-Doc)

Optosmart S.R.L. (Spin Off)

Ing. Armando Laudati

Ing. Giuseppe Parente

GENERAL STRATEGY

- Only one technology: optical fiber sensors
- New materials together with nanotechnologies
- New tools easy to integrate like LEGO blocks
- Continuous innovation
- Bridge between public research and end users
- One goal: safety and security
- Main partners: FINMECCANICA and CERN

OPERATING FIELDS FROM ONE COMMON TECHNOLOGY

- Sensors, microwave photonics e TLC (Selex SI, MBDA, STMicroelectronics)
- Sensors for Railway safety and security (Ansaldo STS)
- Underwater acoustics and monitoring (Alenia WASS)
- Medical and biology applications
- Musical innovation
- Civil engineering

SOME APPLICATIONS CURRENTLY IN PROGRESS

- Optoacoustic underwater sensors (Alenia WASS)
- Railway security (Ansaldo ASF)
- Seismology and territory (seismic poles)
- Musical instruments
- Structural, environmental and food applications (aerospace, CERN, civil)
- Medical

A new Public Private Lab.

Optoelectronics technologies for

Innovative industrial applications

PROGRAMMA OPERATIVO NAZIONALE

RICERCA E COMPETITIVITÀ 2007-2013

Regioni della Convergenza

Campania, Puglia, Calabria, Sicilia

ASSE I - SOSTEGNO AI MUTAMENTI STRUTTURALI

OBIETTIVO OPERATIVO: RETI PER IL RAFFORZAMENTO DEL POTENZIALE SCIENTIFICO-TECNOLOGICO DELLE REGIONI DELLA CONVERGENZA

I AZIONE: DISTRETTI DI ALTA TECNOLOGIA E RELATIVE RETI

II AZIONE: LABORATORI PUBBLICO-PRIVATI E RELATIVE RETI

Partner Pubblici

Centro Regionale Information Communication Technology (CeRICT) scrl,

Università degli Studi di Napoli "Federico II":

- Dipartimento di Ingegneria Biomedica, Elettronica e delle Telecomunicazioni (DIBET)
- Dipartimento di Informatica e Sistemistica
- Dipartimento delle Scienze Biologiche
- Dipartimento di Scienze Fisiche

Istituto Nazionale Geofisica e Vulcanologia (INGV)

Consiglio Nazionale delle Ricerche

- Istituto per l'Ambiente Marino e Costiero (IAMC): Campania e Sicilia
- Istituto per i Materiali Compositi e Biomedici (IMCB)
- Istituto per il Rilevamento Elettromagnetico dell'Ambiente (IREA)

Agenzia Nazionale per le Nuove Tecnologie, l'Energia e lo Sviluppo Economico Sostenibile (ENEA)

Istituto Nazionale di Fisica Nucleare (INFN)

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DiT

Private Partners

AnsaldoSTS
A Finmeccanica Company

WASS
A Finmeccanica Company
Whitehead Alenia Sistemi Subacquei

BTP tecno

SOLVENDO
SOLUZIONI INFORMATICHE E TECNOLOGICHE

research for innovation

GeoLab S.r.l.
MARINE SURVEY

optosmart

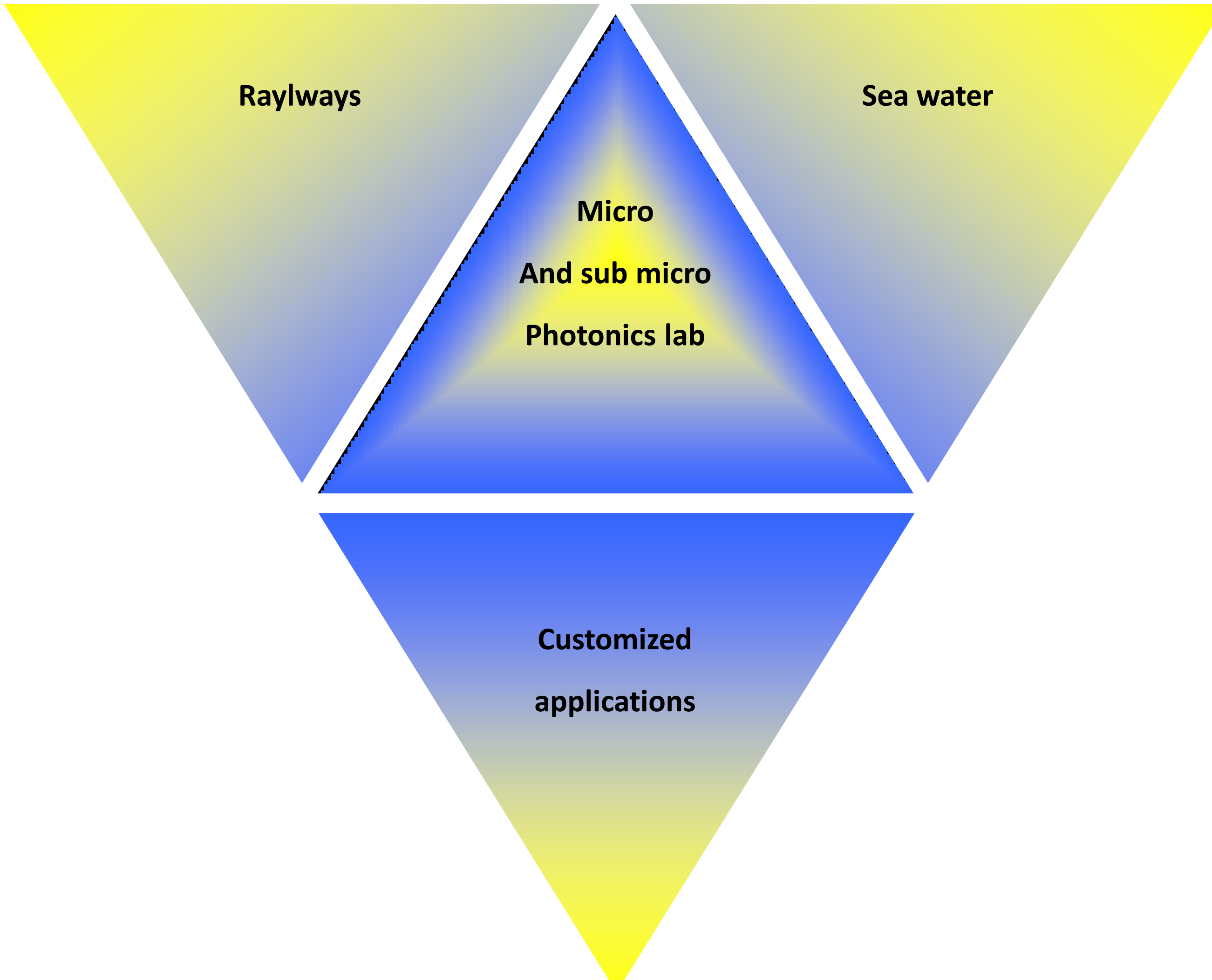
MOM

Other private companies

- CRIT Research™
- AITEK

- Klyma
- Reglass
- Tydockpharma
- Fast

Basic structure of the laboratory

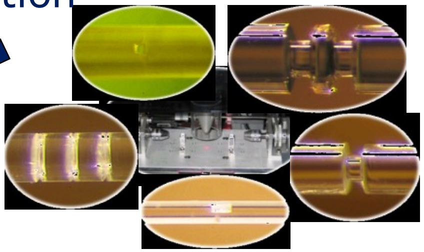


Optoelectronics innovative applications

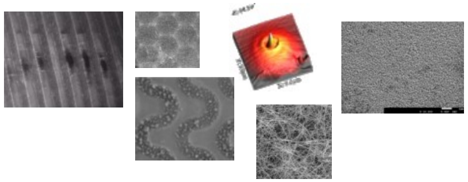
- Local Micro- and nano- structuration

Nano-machining

UV MICROMACHINING

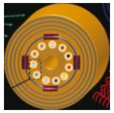


- Material Integration and Patterning

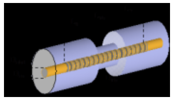


Metal Oxides, Carbon Nanotubes, Nanobelts, Nanowires, Organic materials, Polymers, Metal Particles, Electro-Optic Materials…

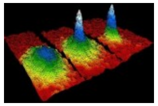
- Advanced All-in-Fiber Devices



Multifunctional Sensors



Optical Modulators



Optical Delay Lines

…and many others!!!

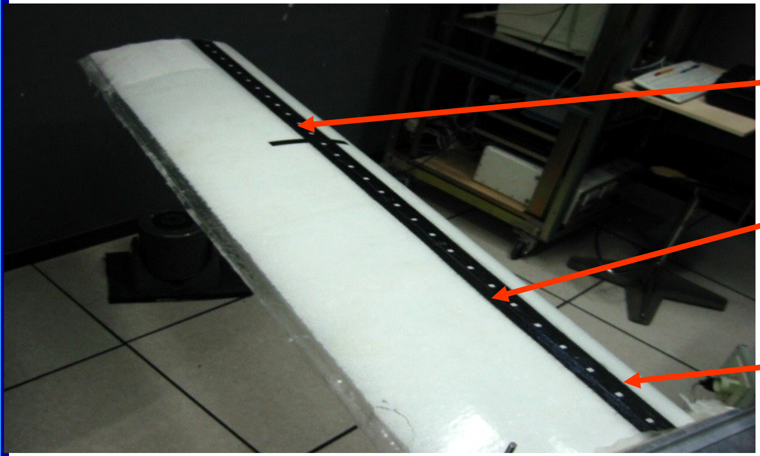
Main lines:

Raylways

Sea water

Customized applications

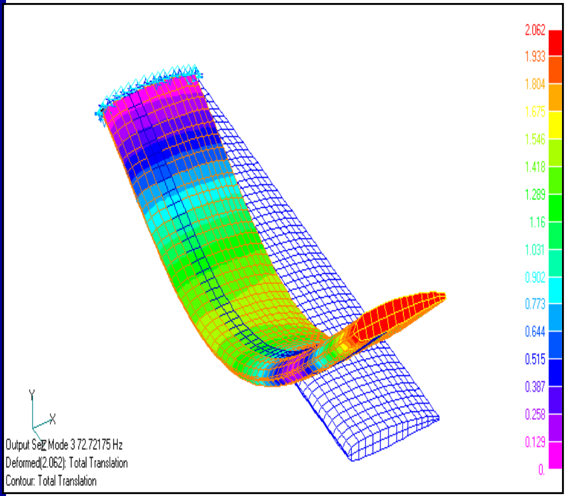
Modal Analysis Tests on a Composite Aircraft Model Wing



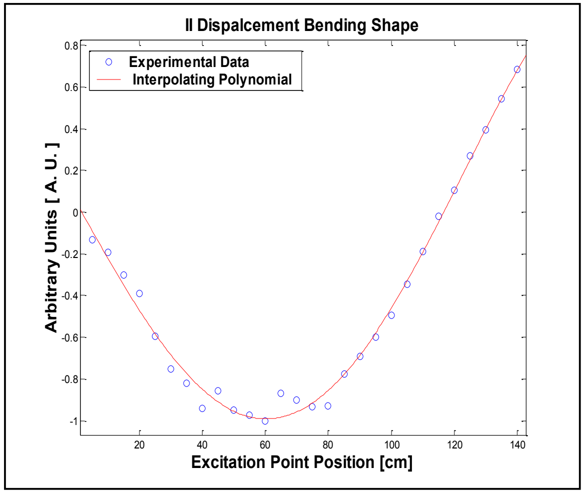
N°4 FBGs Embedded within Spar, Parallel to Wing's Axis

29 Excitation Points for Experimental Measures

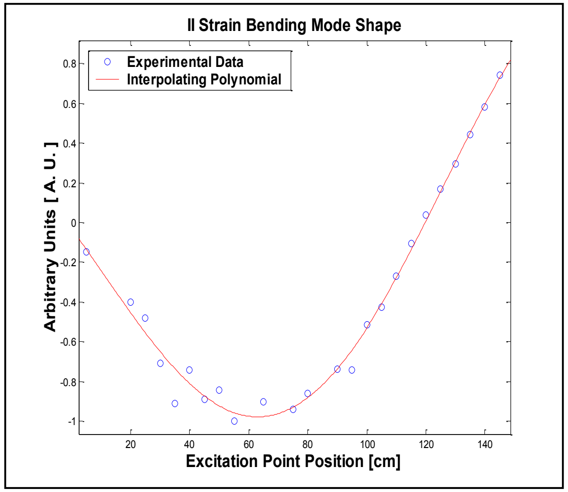
N°4 Uni – Axial Accelerometers Bonded to Wing's Surface



Simulation



Accelerometer



FBG Output

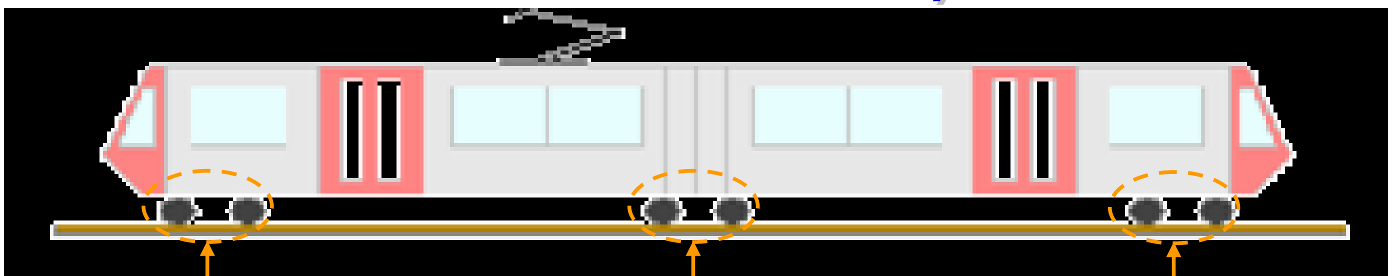
Fiber Bragg Grating Sensors for Railway Monitoring

In field demonstration of FBG Technology as Valuable Tool for Railway Monitoring

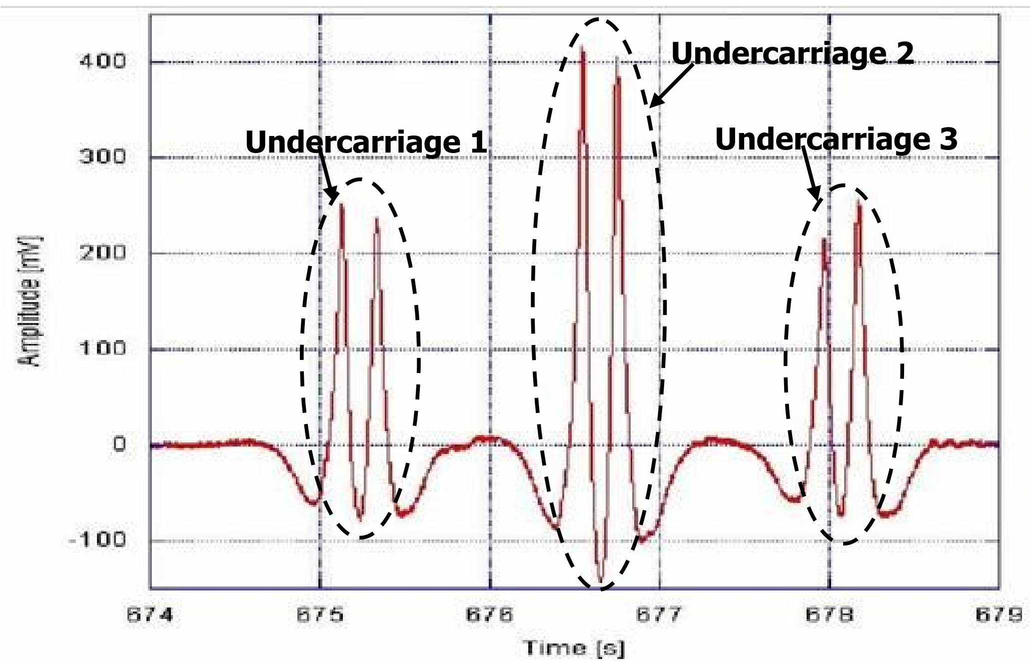
EU Patent Pending

Sites: Genova Nervi, Tel (Valdisole), Sezze Romano

Smart Railways



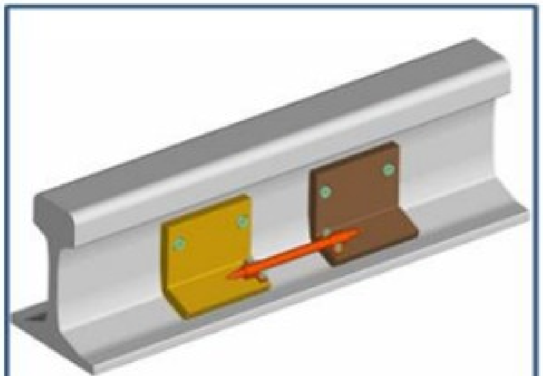
Undercarriage 1 | Undercarriage 2 (engine compartment) | Undercarriage 3



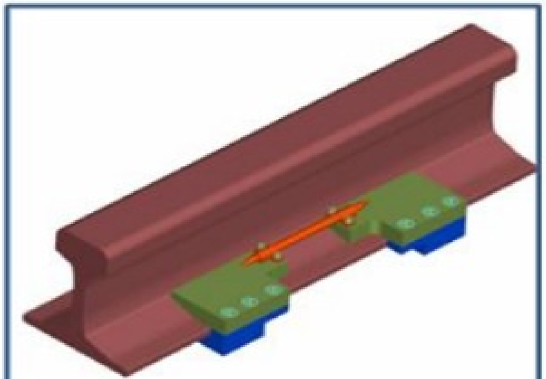
A Single FBG element can provide useful information about:

- ***occupation state,***
- ***train velocity,***
- ***acceleration,***
- ***weighing in motion,***
- ***axle counting***

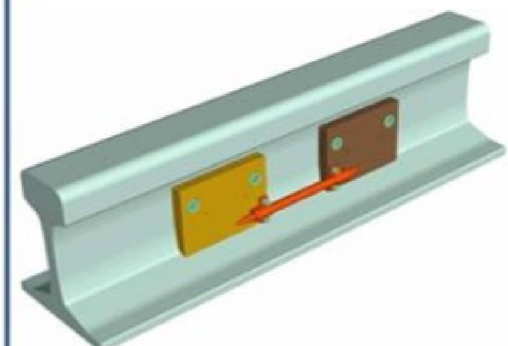
Solutions E - D - F



Solution E
(holes)



Solution D
(no holes)



Solution F
(holes)

Image of the Sensors Installation

FBG packaged in mettallic holders along the railway

Opto-Acoustic Sensors for Underwater Applications

OPTOELECTRONIC AND SMART SYSTEMS

A Finmeccanica Company

CENTRO REGIONALE
INFORMATION COMMUNICATION TECHNOLOGY
CERICT SCRL

Fiber optic hydrophones (electro-acoustic transducer) for military, environmental and industrial underwater applications based on FBG technology integrated with polymeric materials

EU Patent Pending

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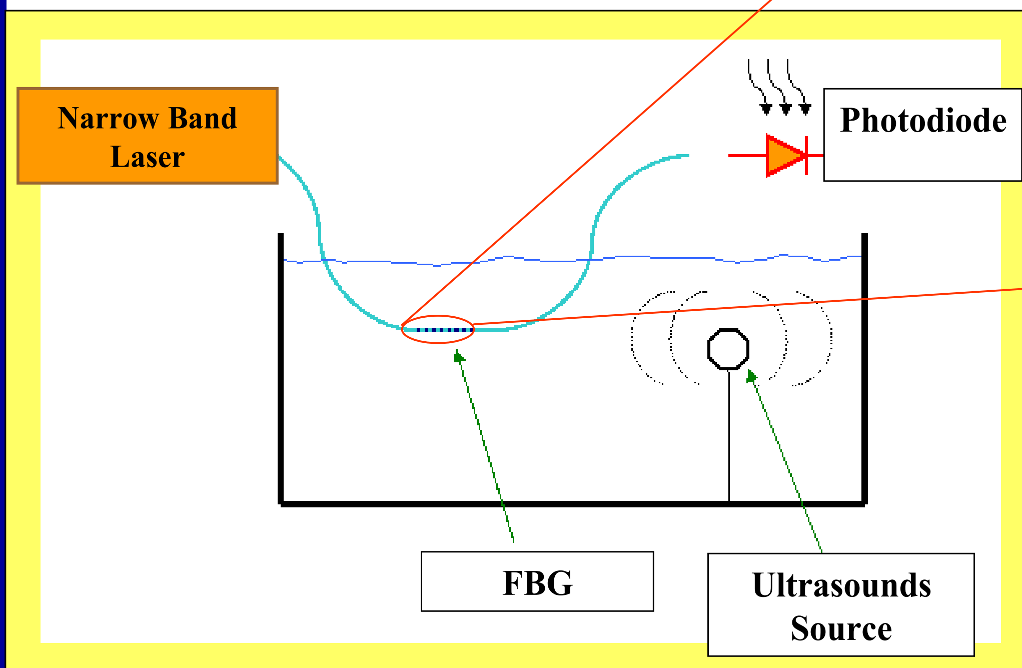
Università degli Studi del Sannio

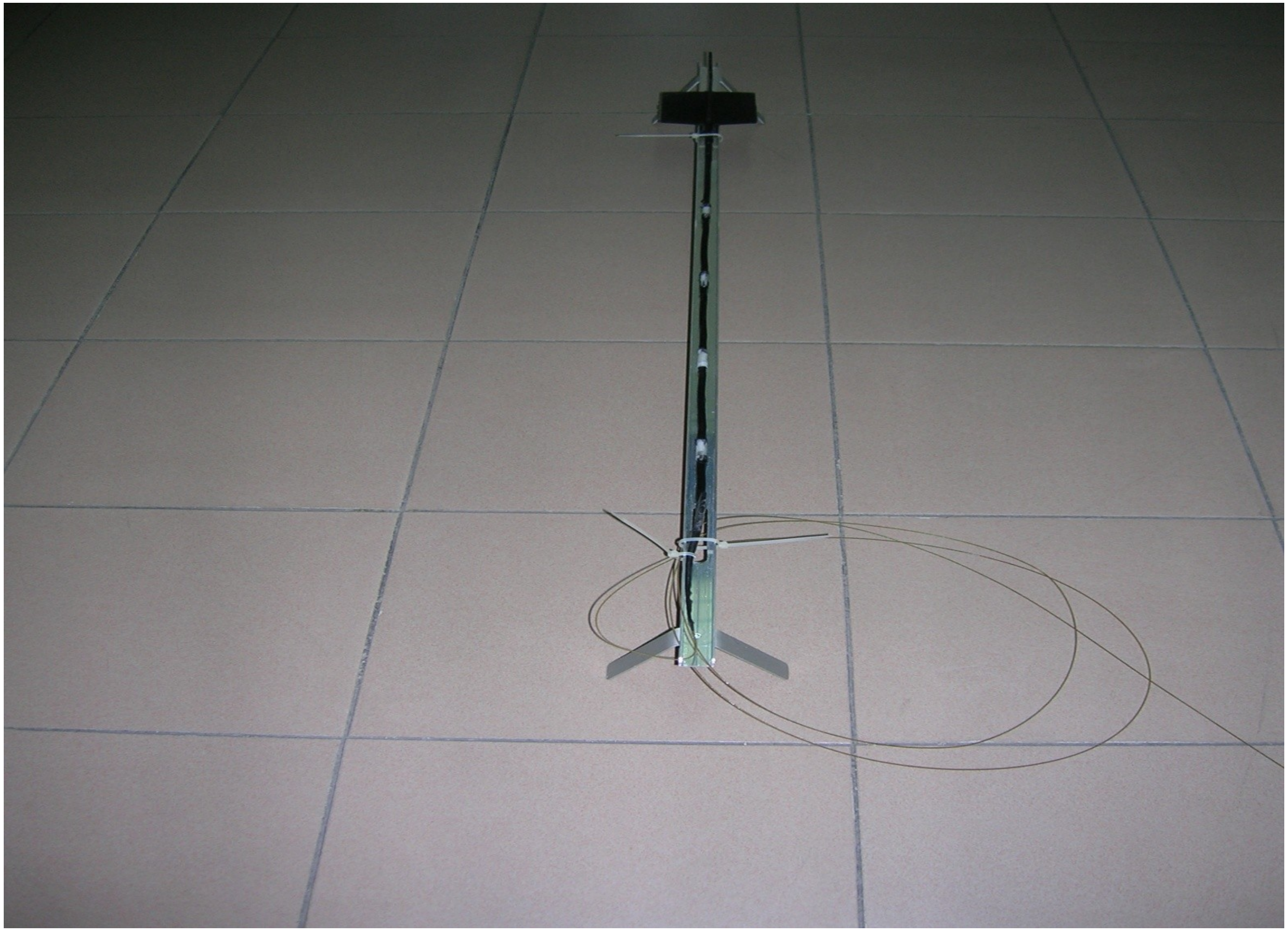
Ultrasound Wave Detection in Fluids

Packaged FBG for Enhanced Performances



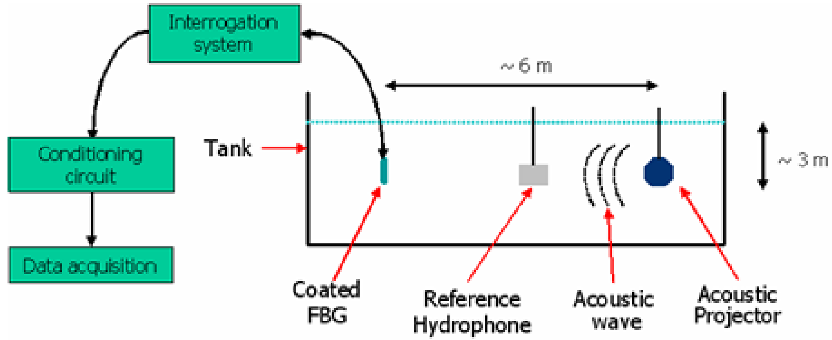
patent filed with Alenia WASS and with OPTOSMART

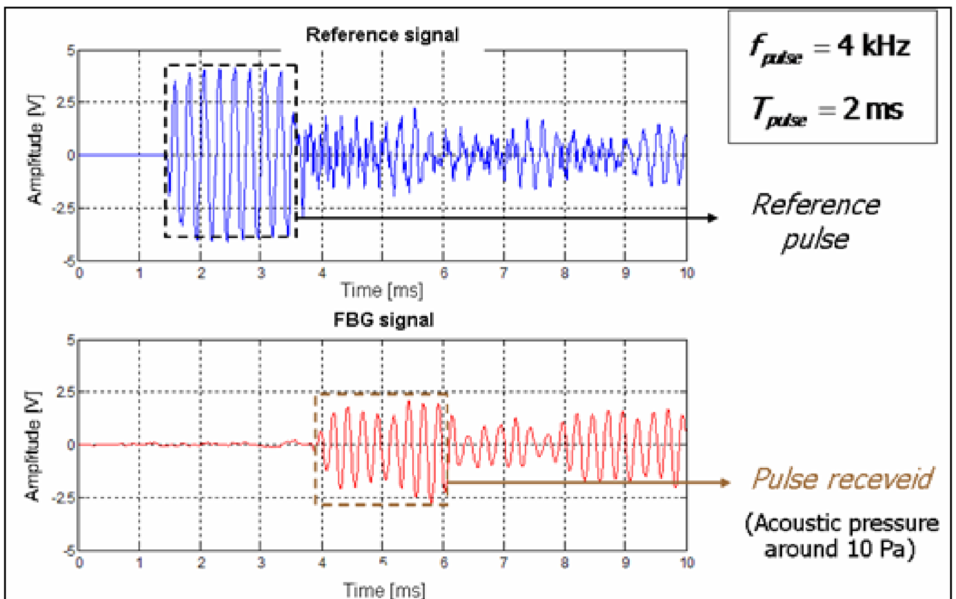
FOUR ELEMENT SPENDING ANTENNA



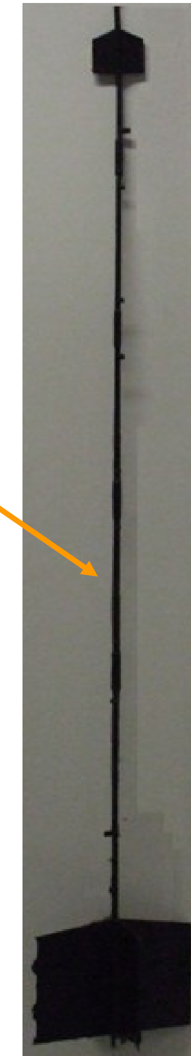
Opto-Acoustic Sensors

Fiber optic hydrophone





Linear Array (4 elements)



Resin & Mortar
Process Cure Monitoring

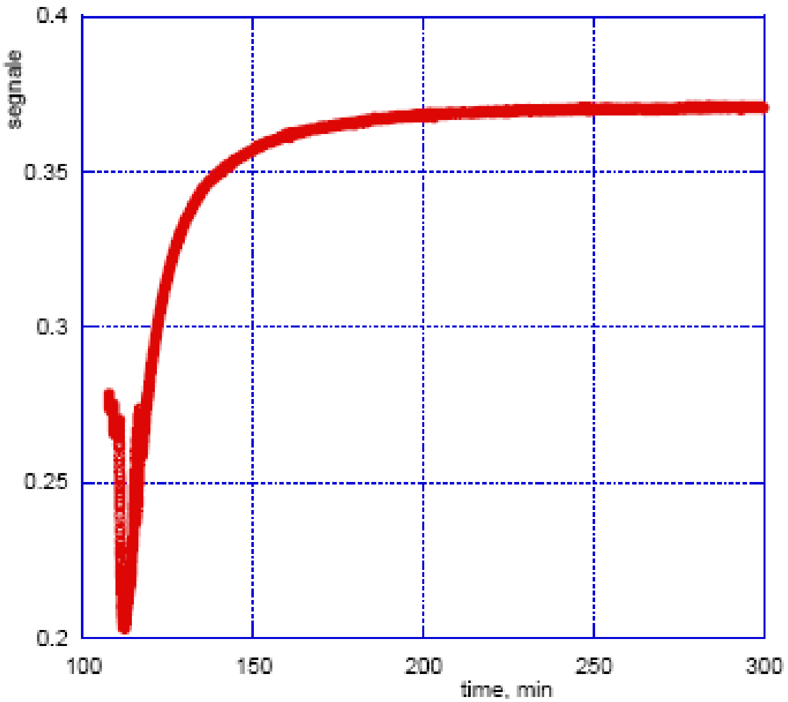
OPTOELECTRONIC AND SMART SYSTEMS

Use of fiber optical sensors for process cure monitoring

Resin & Mortar
Process Cure Monitoring

Resin Cure Monitoring

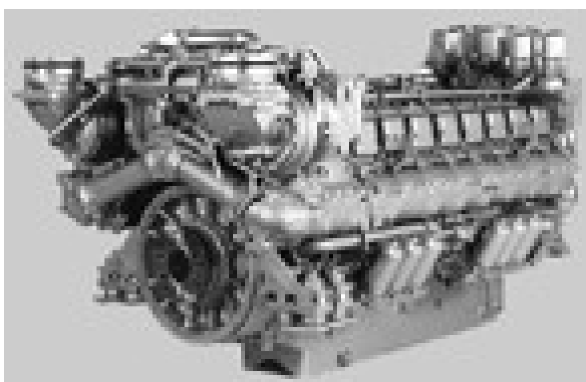
Complete cure of the **resin** after 5 hours about



Vibrational Spectroscopy on Naval Engines

optosmart

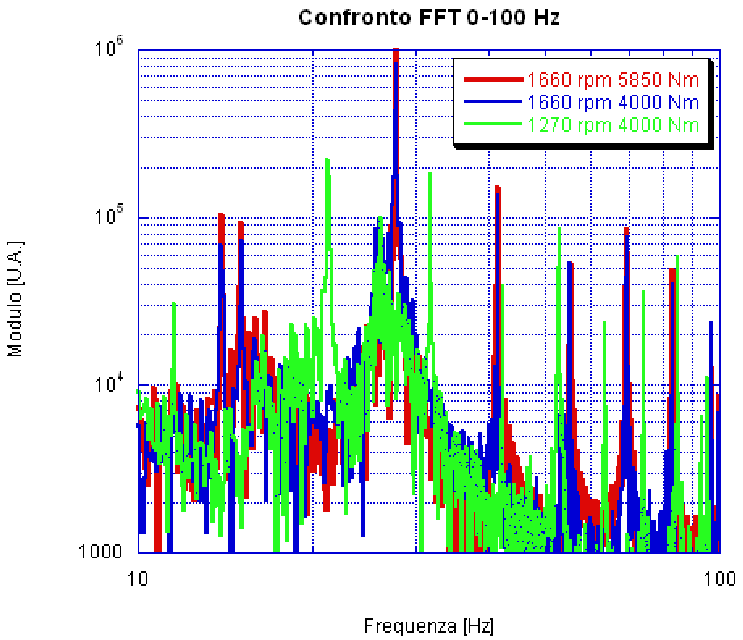
OPTOELECTRONIC AND SMART SYSTEMS

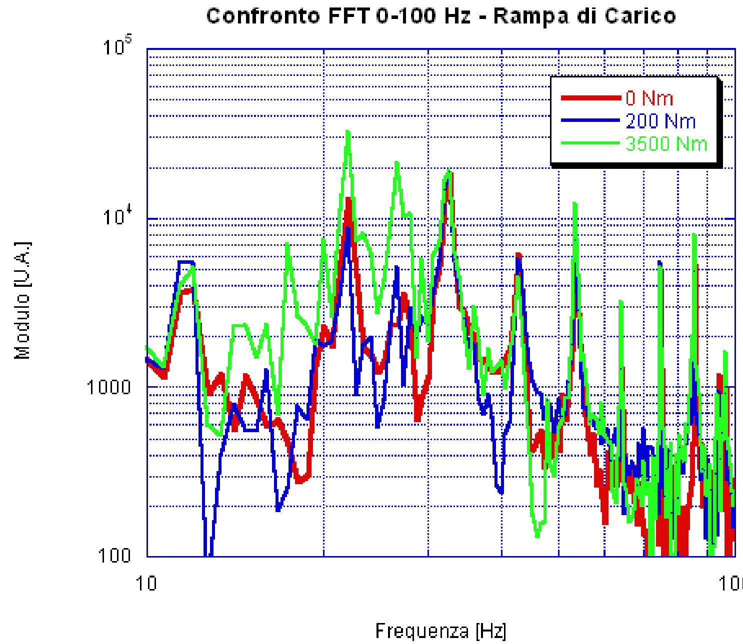


Tests conducted on MTU Engines used by Grimaldi Ferries

Use of FBGs sensors for vibration monitoring in marine engines for early fault detection

Vibrational Spectroscopy on Naval Engines

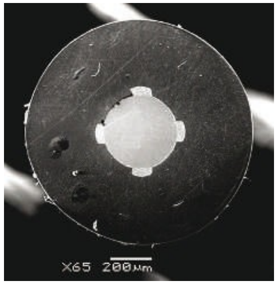




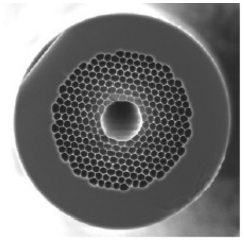
The retrieved spectra contains resonant frequencies typical of the subcomponents included in the marine engine,

Operative conditions or damages of these components significantly changes the vibration spectra

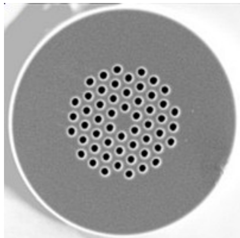
Multimaterial and Microstructured Optical Fibers



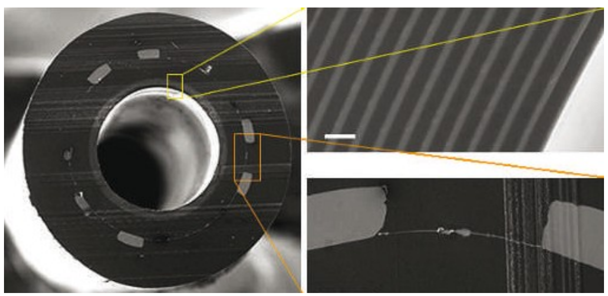
Metal-Semiconductor-Insulator Fiber Devices



Hollow-core fibres

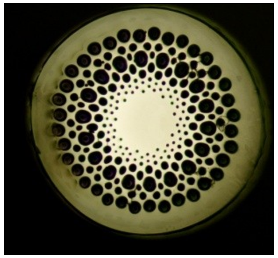


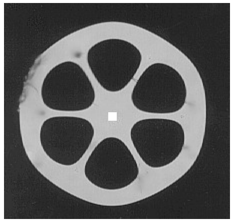
Solid-core fibres



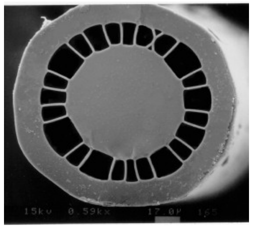
Self-monitoring hollow-core fibres

Plastic Microstructured Optical Fibers

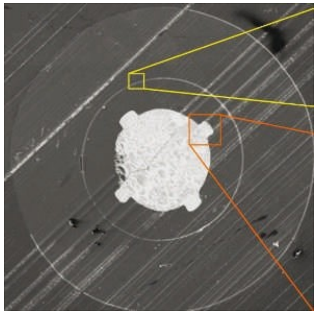




Grapefruit fibres

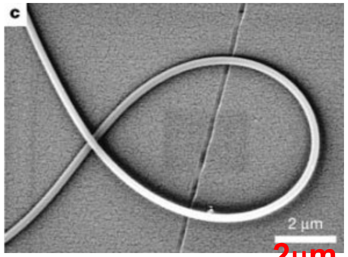


Air-clad fibres

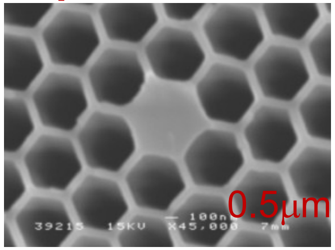


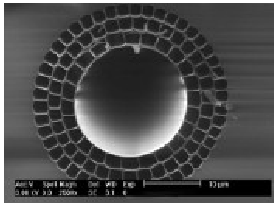
Narrow-band Photodetecting fibres

Nanowires



Tapered Fibers





Air-Silica Bragg Fibres

Many Fibers for Several Applications...

Applications

- High power delivery
- Super-continuum Generation
- Non-conventional wavelengths
  - ✓ Microstructured optical fibers for terahertz wave propagation
- High power pulse compression
- Telecom
- Gas based non-linear optics
  - ✓ Raman; high-order harmonic generation…
- Particle guidance (through radiation pressure) for Life Science Applications
- Physical, Chemical and Biological Sensing