Development of innovative fiber optic magnetic field sensor for harsh environments applications

Francesco Fienga

Tutor: prof. Giovanni Breglio
co-Tutor: eng. Salvatore Buontempo

Phd ITEE, XXIX Cycle - first year presentation

Who am I?

I received the MSc. in Experimental Particle Physic the 17th July 2013.

From April 2013 to March 2014 I worked at CERN being involved in the upgrade of the CMS detector.

From April 2014 I started my PhD in Information Technology and Electrical Engineering at the University of Naples Federico II.

From June 2014 to February 2015 I received a scholarship as part of the research project VEM – Virtual Energy Management, CUP: E61H13000000008 on the topic *“Studio finalizzato alla definizione e progetto di sistemi optoelettronici”*, Rif. Borsa DIETI 14/2014, Prot. 2014/0050962.

My research activity is focused on the development of innovative fiber optic sensors to be used in harsh environment such as the particle physics detectors and accelerator. For this purpose I’m collaborating with the CERN group of fiber optic sensors, with the IMCB-CNR and with the INFN-Napoli.

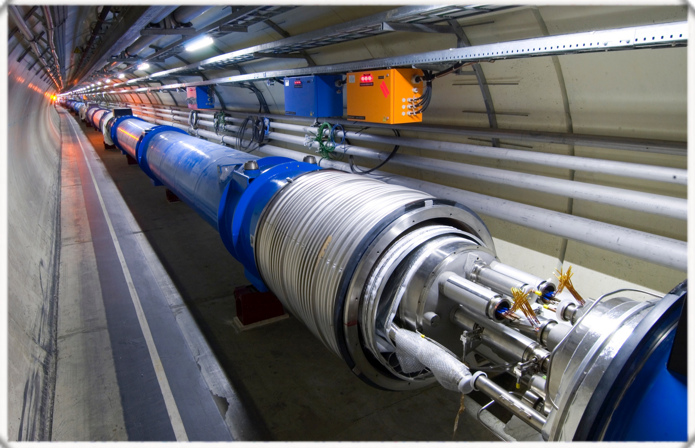
My tutors are prof. Giovanni Breglio (UNINA) and eng. Salvatore Buontempo (CERN/INFN).

Research Activity

Development of innovative fiber optic magnetic field sensor for harsh environments applications.

Motivation:

Monitoring and mapping high magnetic field in environments with high level of ionizing radiation (CERN facilities, Nuclear power plants, …).

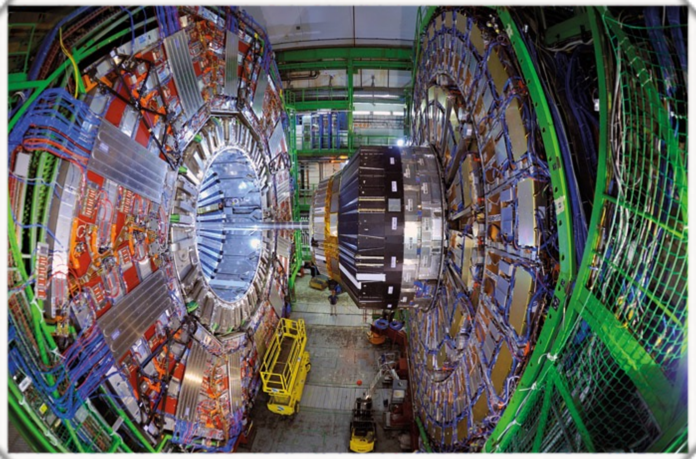


Key features:

radiation hardness
high multiplexing capability

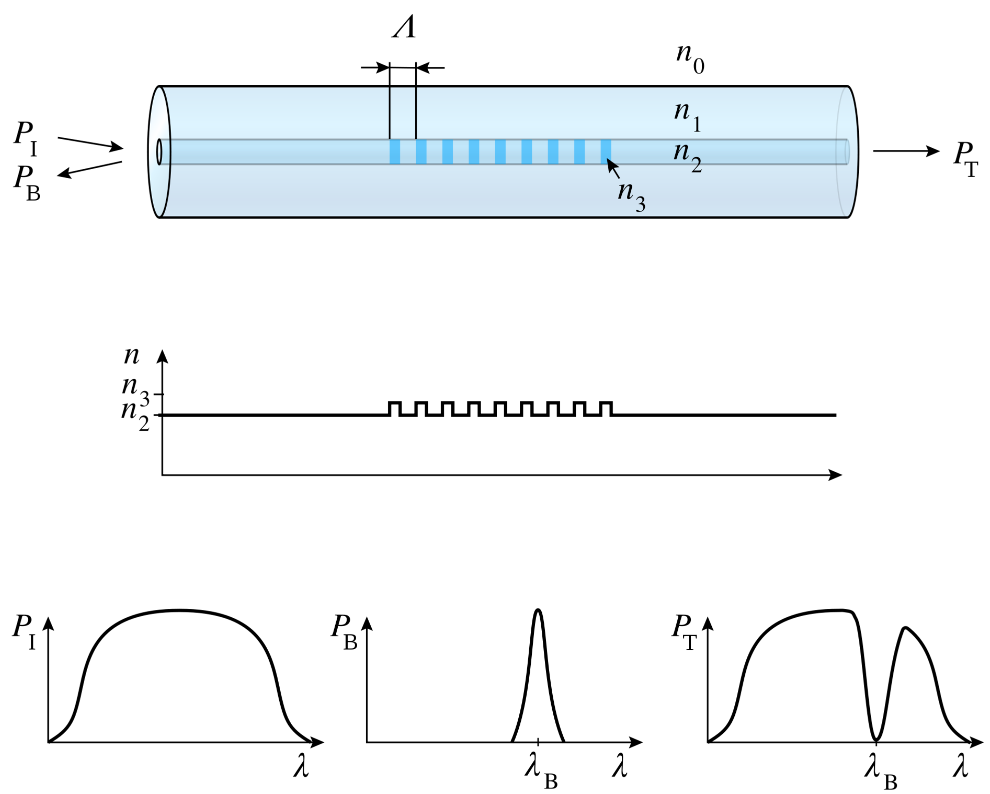
Selected candidate:

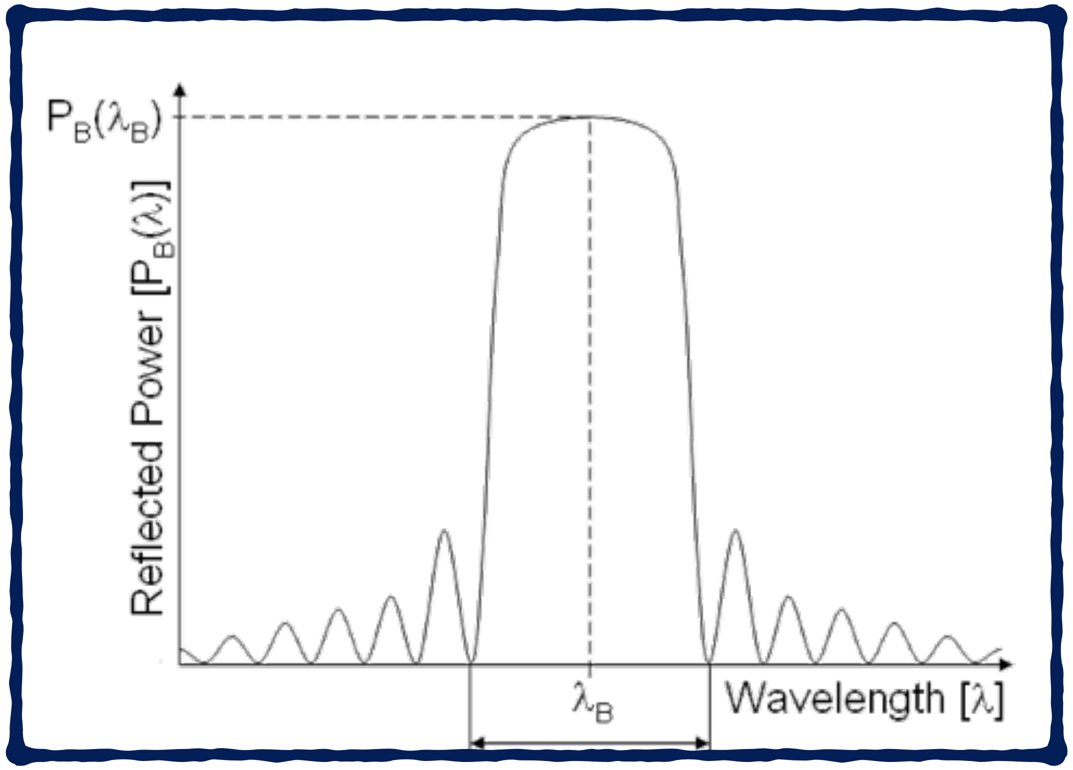
Fiber Bragg Grating sensors



- Ionizing radiation produces radiation-induced attenuation in optical fibers.
- Being spectrally encoded, the FBG sensors are insensitive to intensity modulation of the optical carrier and broadband-radiation-induced losses.
- It's possible to realize with them reliable sensors for various harsh environment applications and extended distance monitoring systems.

STANDARD FIBER BRAGG GRATING





A Fiber Bragg Grating is made by periodical changes of the Refractive Index (RI) in the glass core of a single-mode optical fiber (SMF-28).

$$\lambda_B = 2n_{eff}\Lambda$$

By measuring the changes in λ_B is possible to use the FBG sensors as strain-gages and as thermometers:

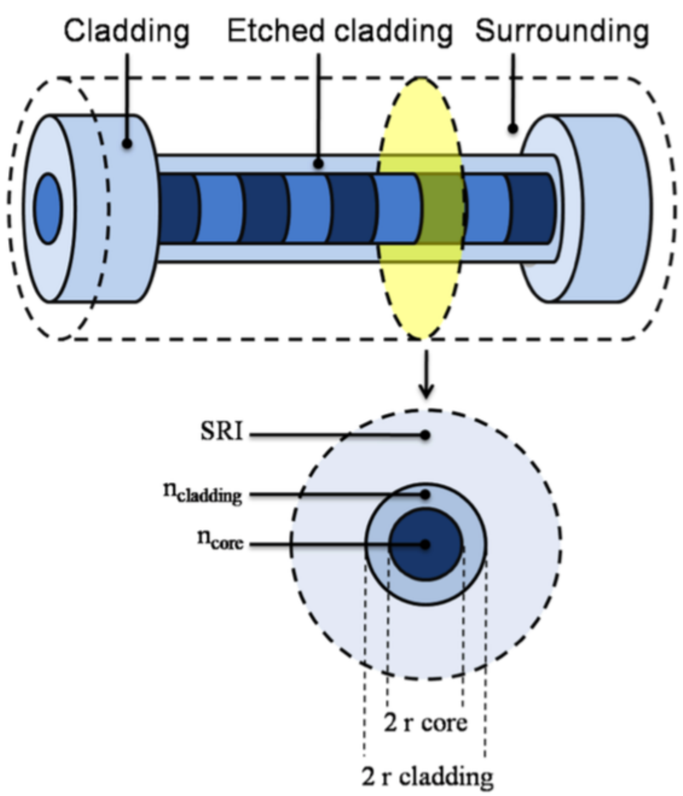
$$\frac{\Delta\lambda_B}{\lambda_B} = (1-p_e)\epsilon + \left(\alpha_\Lambda + \frac{1}{n}\frac{\delta n}{\delta T}\right)\Delta T$$

Direct Strain **[Λ]**
Elasto-optic **[n_{eff}]**

Thermal expansion **[Λ]**
Thermo-optic **[n_{eff}]**

In a standard single-mode optical fiber, **n_{eff}** is not affected by the refractive index of the surrounding medium

FBG Magnetic Field Sensor



But, a Fiber Bragg Grating can also be used as Surrounding Refractive Index (SRI) sensor if the cladding diameter is properly thinned along the grating region.

$$\Delta\lambda_B = 2\left(\Lambda\frac{\delta n_{eff}}{\delta SRI}\right)\Delta SRI$$

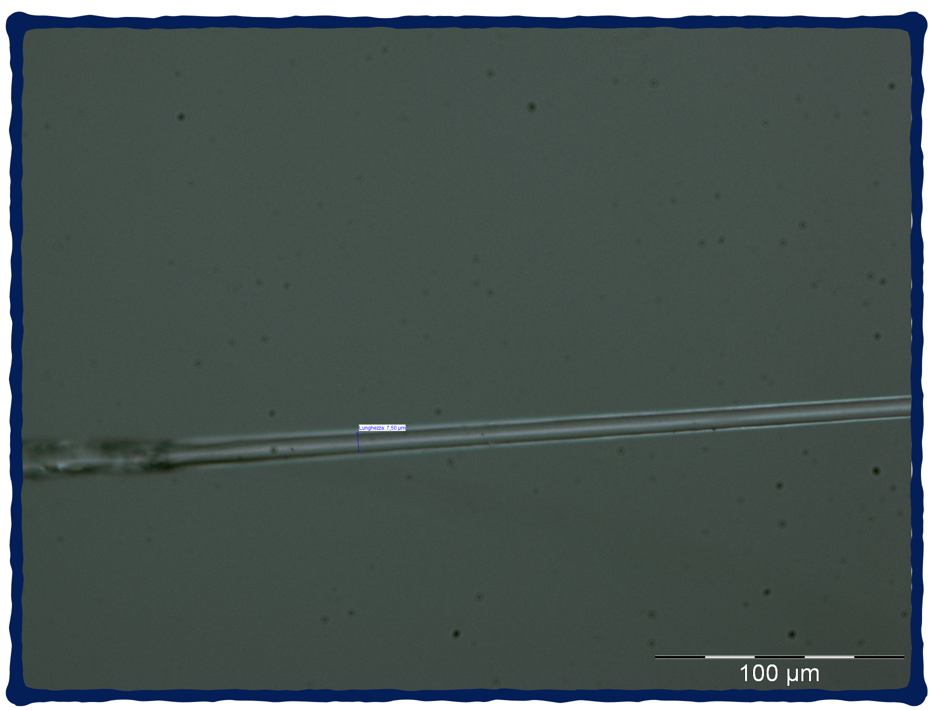
Nanoparticles Fe_3O_4 **magnetic fluid** as surrounding medium.

Stable colloidal solution of ferromagnetic nanoparticles whose behaviors in magnetic fluid are dependent on the external magnetic field, so the refractive index of magnetic fluid is shown to be magnetic field dependent.

$$n = \sqrt{\epsilon_r} = \sqrt{1+\chi}$$

$$\frac{d\chi}{dH} < 0$$

The magnetic fluid's refractive index will decrease when the magnetic field is increasing.



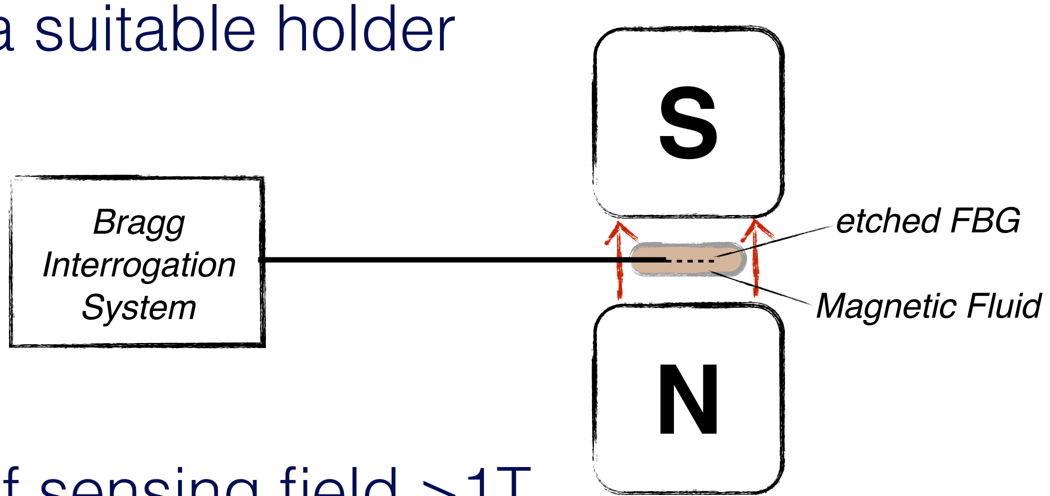
Shift of 86*pm* for a FBG with diameter of 10*um* with a field of 25*mT*

FBG Magnetic Field Sensor

Preliminary Roadmap

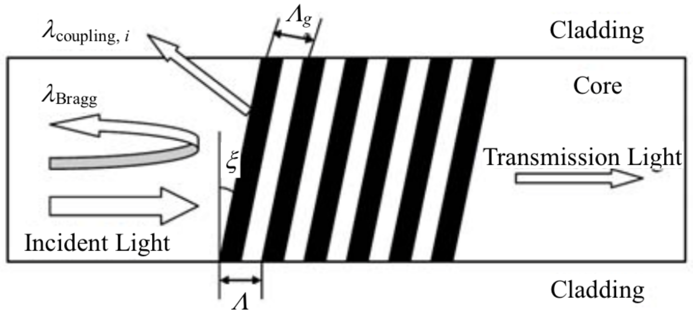
done during the first year:

- Developed a method to etch the fiber (HF acid) in a safety way.
- Developed a procedure to deep the etched FBG into a suitable holder filled with the magnetic fluid.
- First preliminary tests performed at CERN.



to be done in the next months:

- Optimize the FBG fiber diameter to fulfill the request of sensing field >1T.
- Use a short FBG (2mm) to avoid mechanical stability problem.
- Test the response of tilted FBG *(literature study already started)*:
    - no need for etching
    - high sensitivity to SRI
    - cannot be multiplexed



to be done along the second year:

- Implement a mathematical model for the FBG magnetic sensor.
- Test some prototype at CERN

First Year Activity

	Credits First Year								
		1	2	3	4	5	6		
	Estimated	bimonth	bimonth	bimonth	bimonth	bimonth	bimonth	**Total**	**Check**
Modules	**18**					3	2 **+ 9**	**5**	**20 - 40**
Seminars	**13**				4.4		0.8	**5.2**	**5 - 10**
Research	**34**	7	5	5	5	8	5	**35**	**10 - 35**

Modules

- EuroProgettazione (*ad-hoc course*)
- Integrated Photonics (*master course*)
- Three core issues for the internet: things, security and economics (*occasionally provided*)

Seminars

- Nano-carbon based components and materials for high frequency electronics. (4 hours)
- Seminars followed at the Summer School for Early Stage Researchers entitled “Optical fibre sensors: from research to real world” organized by the COST Action TD1001 OFSESA, Novel and Reliable Optical Fibre Sensor Systems for Future Security and Safety Applications. Certificate with the list of the seminars attached. (18 hours)
- Efficient service distribution in next generation cloud networks. (4 hours)

Activity Abroad

Experimental test and measurement campaigns at CERN, Geneva:

- 01/03/2014 - 27/03/2014
- 19/05/2014 - 26/05/2014
- 04/09/2014 - 14/09/2014
- 02/12/2014 - 13/12/2014
- 03/02/2015 - 07/02/2015