PY5021 - 8 Examples

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1. Active sensor bearing
2. Magnetocardiography
3. Mixed sensors
4. Magnetic barcodes
5. Security tags

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www.tcd.ie/Physics/Magnetism

8.1 Active sensor bearing

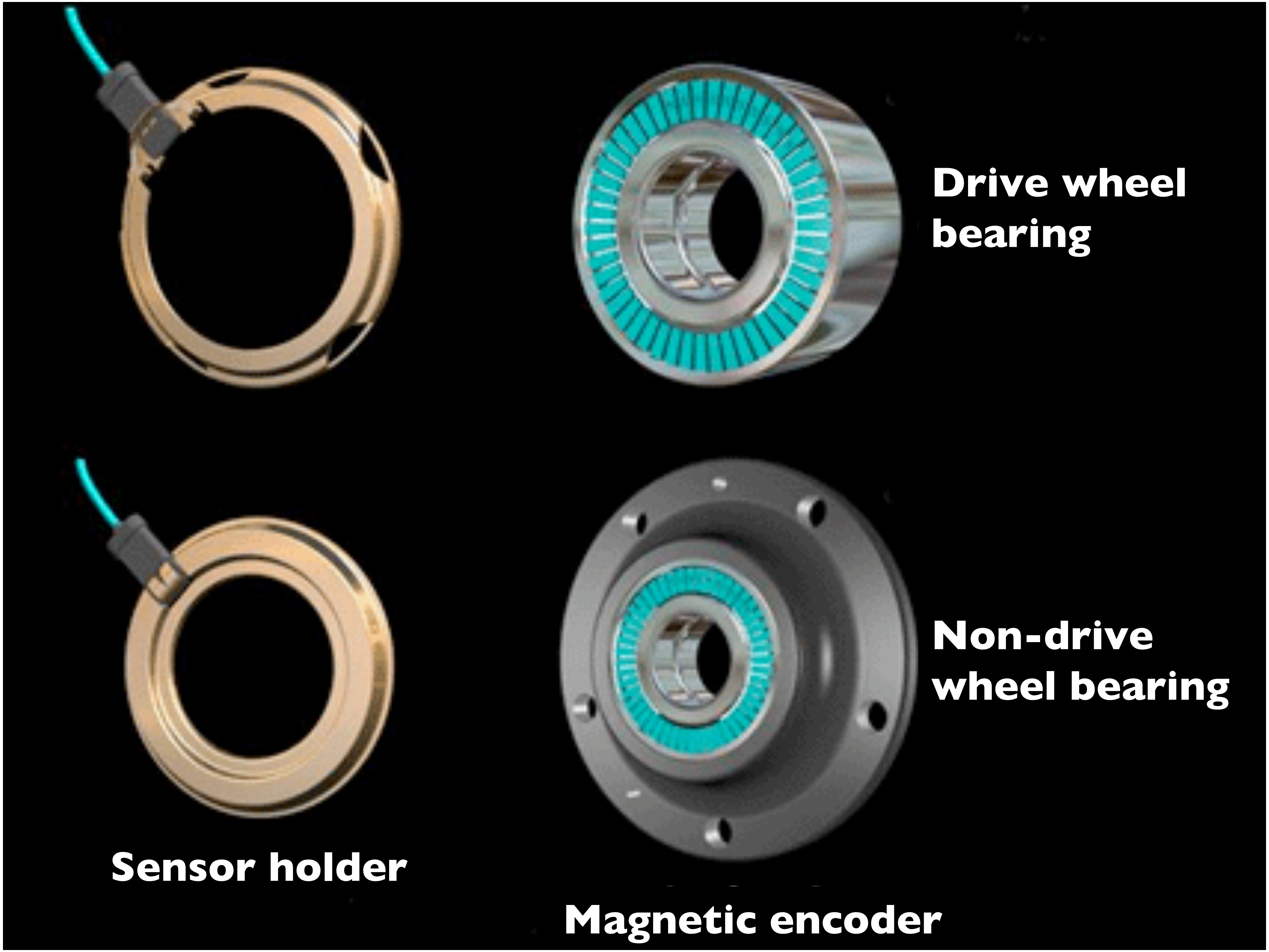
A magnetic tunnel junction (MTJ) sensor built into a rolller bearing which is able to measure precisely the speed of rotation of a wheel. Used in antilock braking systems (ABS)

- Based on a MTJ sensor developed at Spintec, a research and development laboratory belonging to the French Atomic Energy Commission, associated with the University of Grenoble
- Developed by a small company (SNR)
- Destined for a mass-market application

spintec
SPIN IN ELECTRONICS

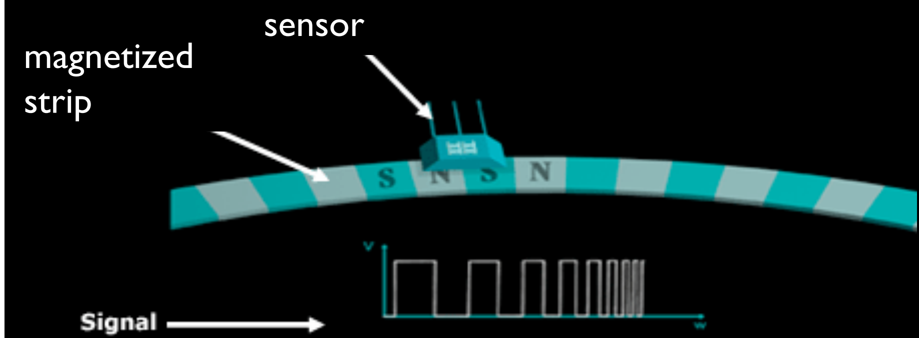
NTN SNR

Le prix Yves Rocard 2010 de la Société Française de Physique


Drive wheel bearing
Non-drive wheel bearing
Sensor holder
Magnetic encoder

ASB Technology (Active Sensor Bearing)

First generation



reads velocity down to v=0

Avoids the wheels locking

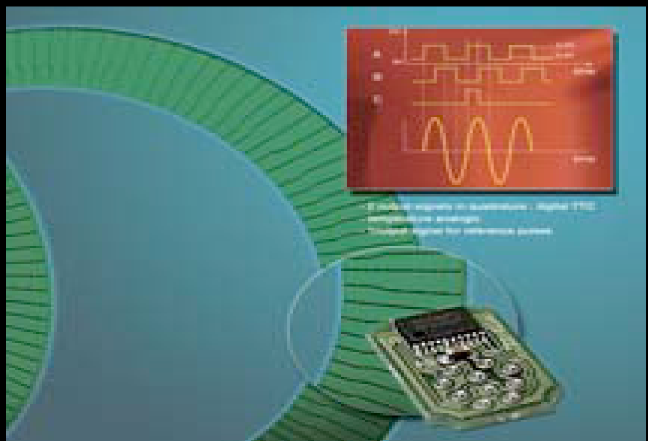
Economical and compact solution

Simplified assembly

Global standard

SNR make 80 000 ASB bearings a day/

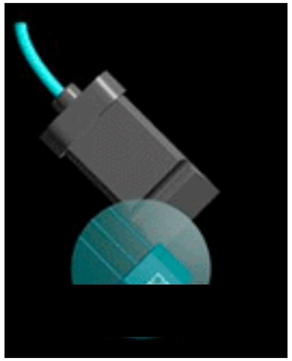
Second generation



Measures position
and angular velocity
(marketed 2008)

For the last 5 years, ten of the most popular vehicles in Europe have been equipped with ASB

Design brief



Replace the first generation of field sensors by a linear senor based on MTJ technology.

- Range of field measured ± 1.5 mT
- Operating temperature range
- Low power consumption
- Linear response
- Improved sensitivity

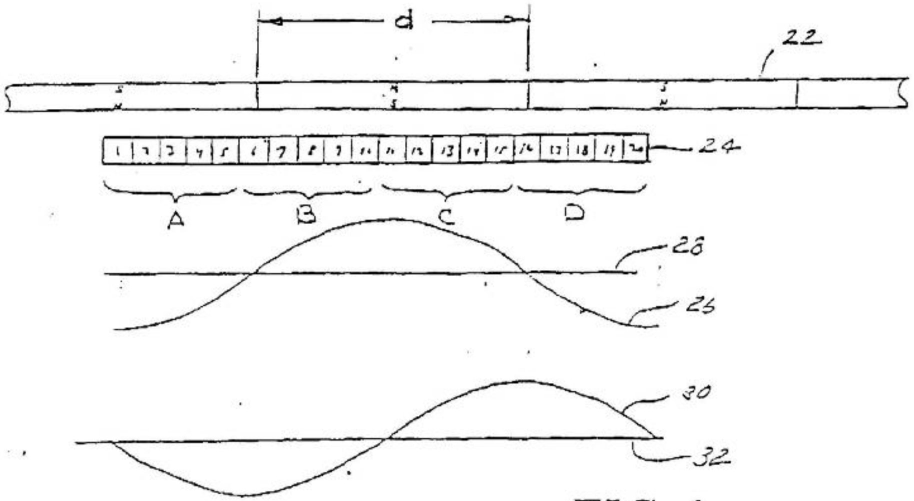
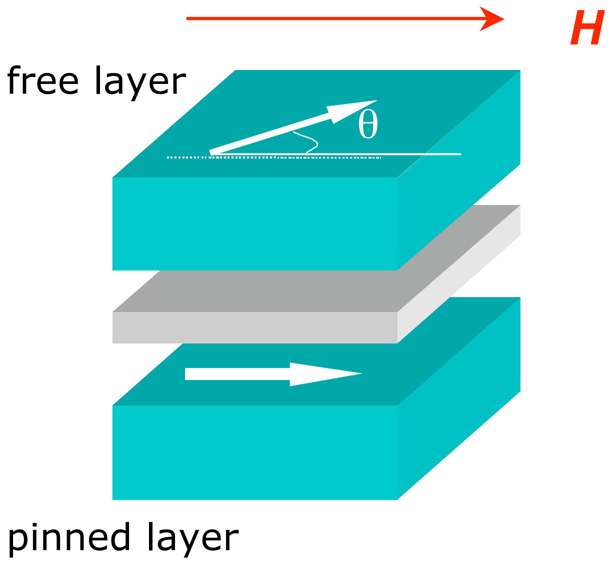


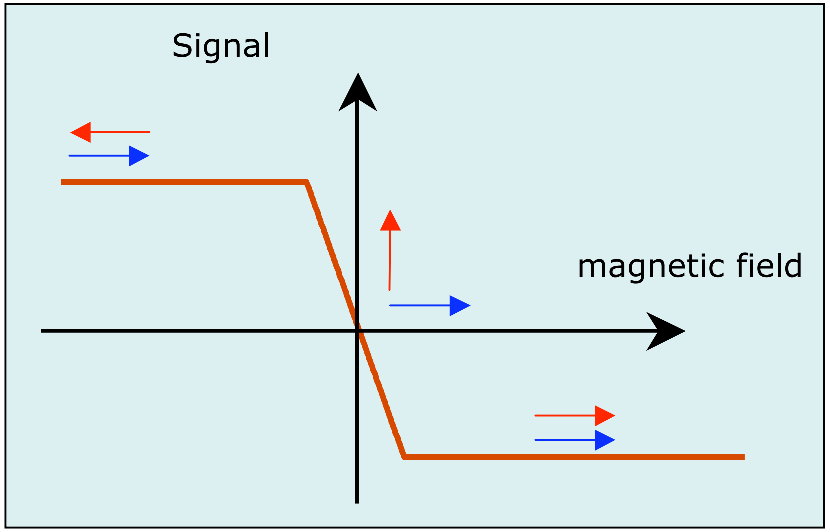
FIG. 2

MTJ sensor



- Two ferromagnetic layers separated by an insulator
- Free layer orientation controlled by magnetic field
- Tunnel current measured perpendiular to the plane

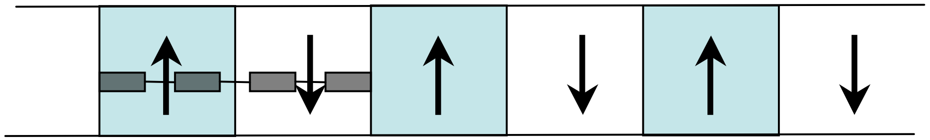
$$R \approx R_0 + \frac{\Delta R}{2}\cos\theta$$

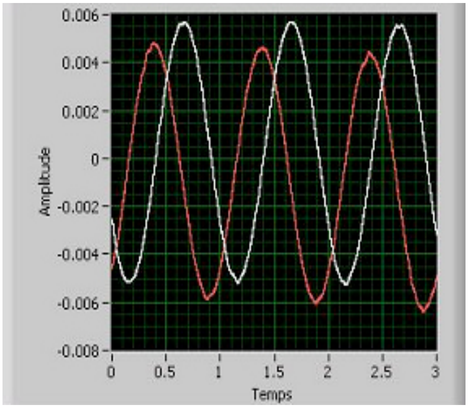


key issue : control the magnitude and direction of the anisotropy

From tunnel junction to sensor

A sensor formed from four sensors, each
separated by 1/4 of the magnetic period





- speed of rotation
- direction of rotation
- Position of the wheel
  (count or use two tracks
  with different periods)

several sensors

+

Vernier effect 11/12

4096 points

per revolution

US 20070159164A1

(19) **United States**

(12) **Patent Application Publication** (10) **Pub. No.: US 2007/0159164 A1**

Hehn et al. (43) **Pub. Date: Jul. 12, 2007**

(54) **MAGNETORESISTIVE SENSOR, COMPRISING A FERROMAGNETIC/ANTIFERROMAGNETIC SENSITIVE ELEMENT**

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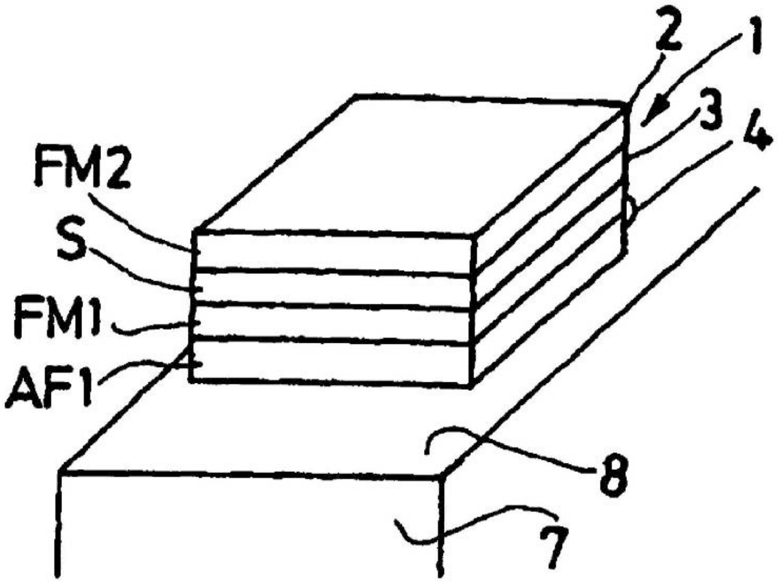
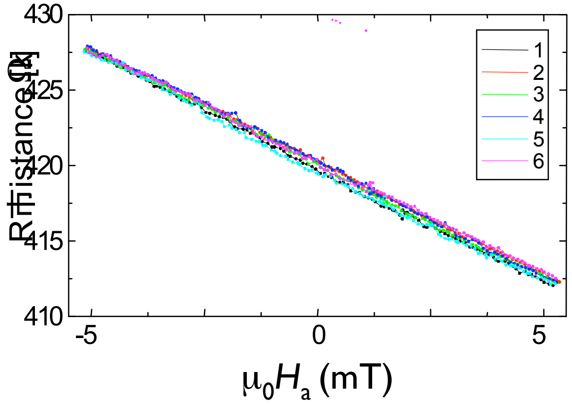
(52) **U.S. Cl.** **324/207.21**

(57) **ABSTRACT**

The invention concerns a magnetoresistive magnetic field sensor comprising a stack (**1**) of a reference element (**2**), a separation element (**3**) and an element (**4**) sensitive to the magnetic field, in which the reference element (**2**) and the sensitive element (**4**) have respectively a first and a second magnetic anisotropy (**5, 6**) in a first and a second direction. The sensitive element (**4**) comprises the superposition of a layer of a ferromagnetic material (FM**1**) and a layer of an antiferromagnetic material (AF**1**) which is arranged in order to obtain a magnetic moment (**10**) whose component oriented in the direction of the field to be measured varies reversibly in relation to the strength of the magnetic field to be measured, and linearly in an adjustable field range. The invention also concerns a use of such a sensor.

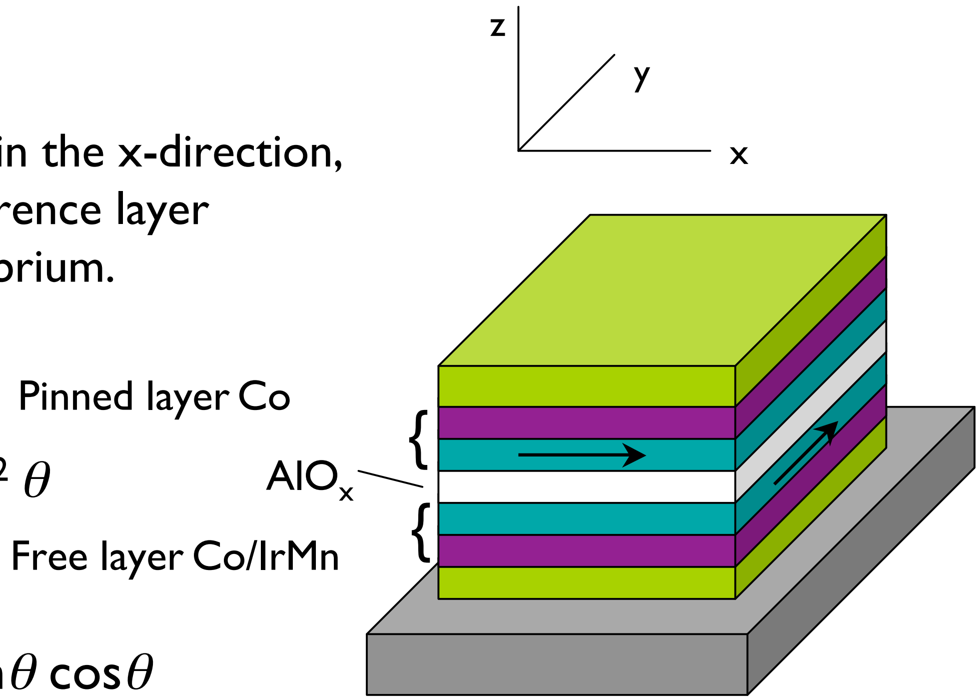


Linear response



$$R = R_0 + \frac{\Delta R}{2}\cos\theta \qquad \cos\theta \approx \frac{H_a}{H_{eff}} \quad \Rightarrow \quad R \approx R_0 + \frac{\Delta R}{2}\cdot\frac{H_a}{H_{eff}}$$

Consider the response to a field applied in the x-direction, which is the direction of the pinned, reference layer
Torque is zero on the free layer in equilibrium.



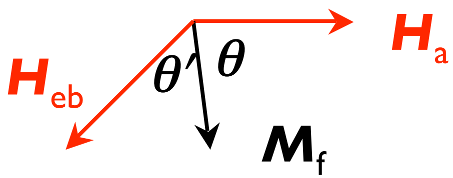
$E = M_f H \cos\,\theta + M_f H_{eb} \sin\,\theta + K_u \sin^2\theta$

$dE/d\boldsymbol{\theta} = 0$

$0 = -M_f H \sin\theta + M_f H_{eb} \cos\theta + 2K_u \sin\theta \cos\theta$

Since $\theta \approx \pi/2$, $\sin\,\theta \approx 1$, $\cos\,\theta$

$\cos\theta = M_f H/[M_f H_{eb} + 2K_u]$

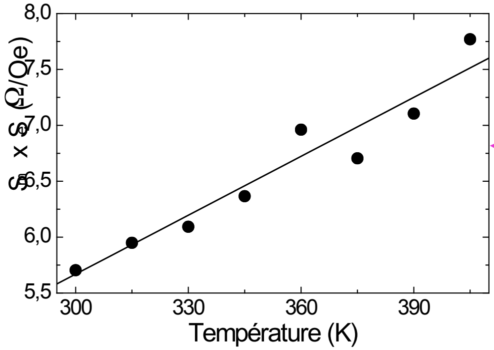


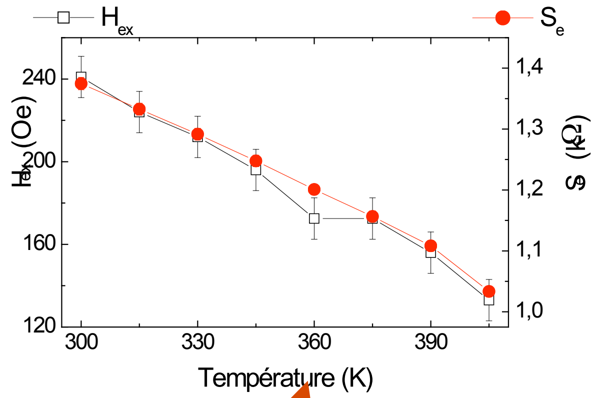
$R = R_0 + \{\Delta R M_f/2[M_f H_{eb} + 2K_u]\}H$ – *linear in H*

When $K_u << M_f H_{eb}$.

$$\boxed{R = R_0 + (\Delta R/2)H/H_{eb}}$$

Thermal drift





$$R = R_0 + \frac{\Delta R}{2} \cdot \frac{H_a}{H_{eb}}$$

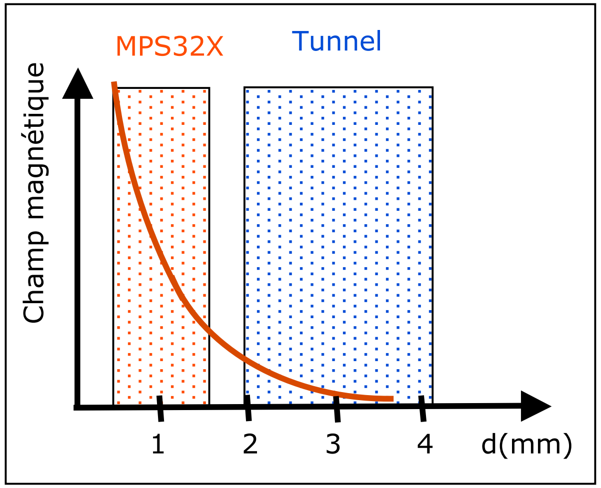
Temperature variation < 0.01% K^{-1}

Exchange bias decreases with temperature, but the deflection of the free layer increases correspondingly.

From a sensor to a product

Phase 1 Produce a laboratory demonstrator

Graduate student
G. Malinowski 2006

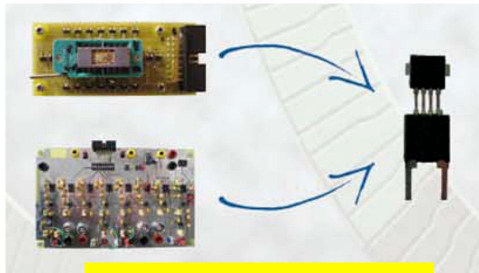


- Inproved sensitivity
  - increase the distance from the magnet from 1 to 3 mm
  - paise the tolerences for sensor position
  - Ue a cheaper magnet

- Electrical power consumption reduced by a factor 100
- Wider temperature range
- Improved signal/noise ratio

Phase 2 Develop an industrial process

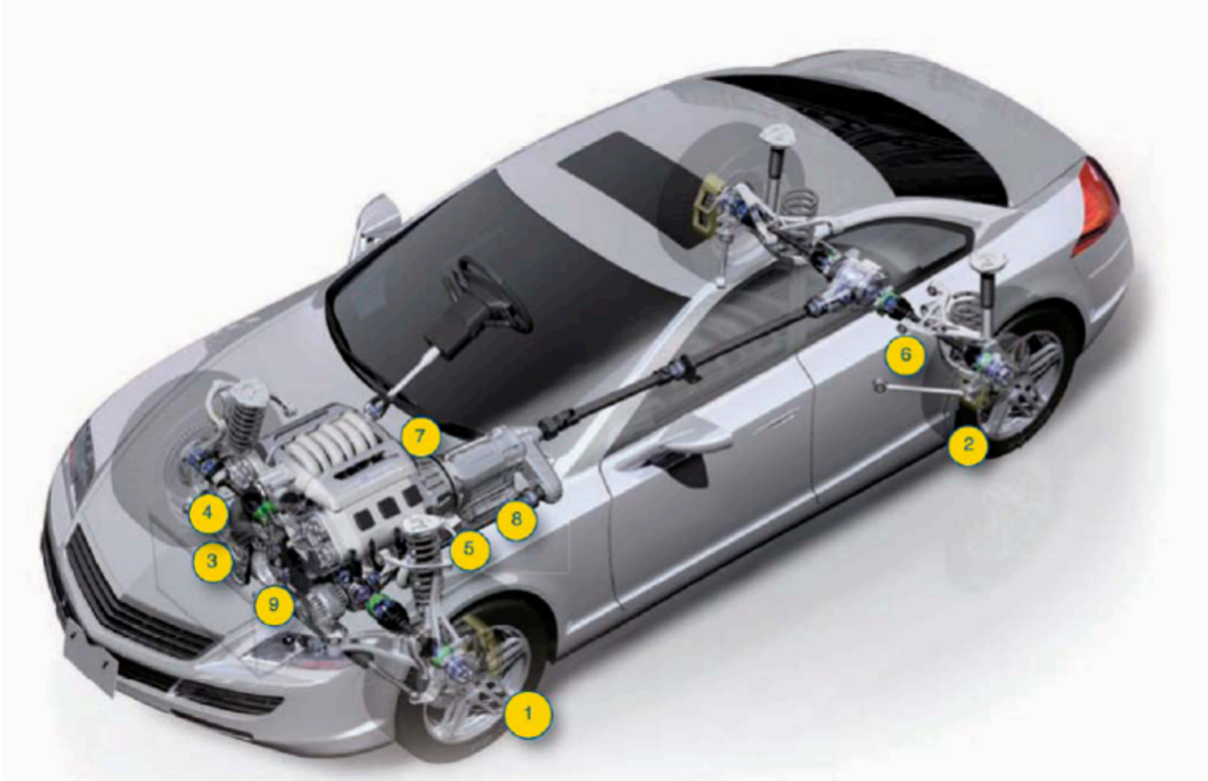
Make the sensor in an industrial fab
Produce an integrated prototype



CAMEL
project

Phase 3 Manufacture

Product to market
late 2012


1
2
3
4
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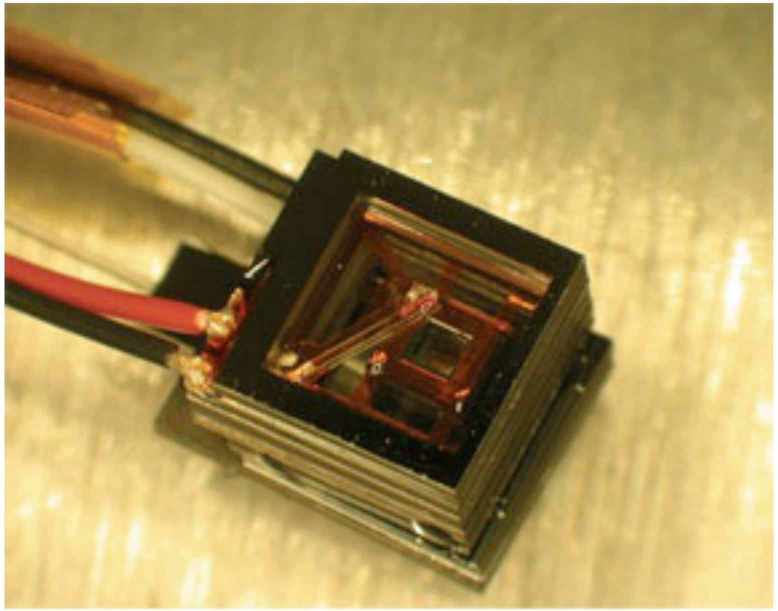
9

8.2 Heart sensor

A miniature Rb vapour magnetometer was developed at NIST. It uses a small ~ 4 mm cell containing 10^{11} Rb atoms, and a low-power laser.

The sensor is able to record the cardiac activity of a subject at a distance of 5 mm above the left side of the chest. Fields are of order pT from the heartbeat.

The device was tested in the magnetically-shielded room in Berlin. While not as sensitive as a SQUID, the device shows that alkalai vapour magnetometers can be miniaturized, and operate in ambient conditions.



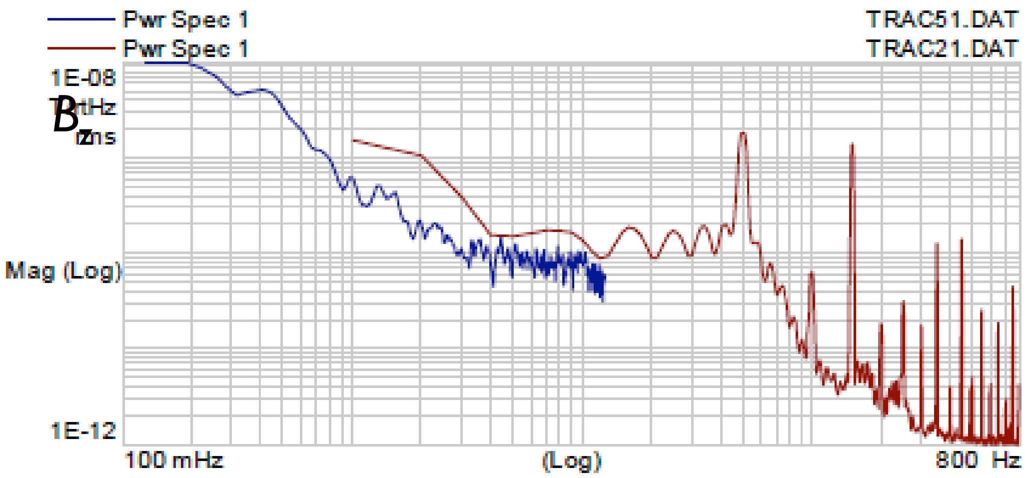
NIST's miniature magnetic sensor is about the size of a sugar cube. The lid has been removed to show the inner square cell, which contains a gas of rubidium atoms. The diagonal bar is an electrical connection to the cell's heaters, which are powered by the red, black and white electrical wires. The clear optical fiber extending from the middle bottom of the sensor connects to a control box. Credit: S. Knappe/NIST

Another biomedical application is magnetic relaxometry, where magnetic nano-particles are localized and imaged in the body via their transient magnetic relaxation.

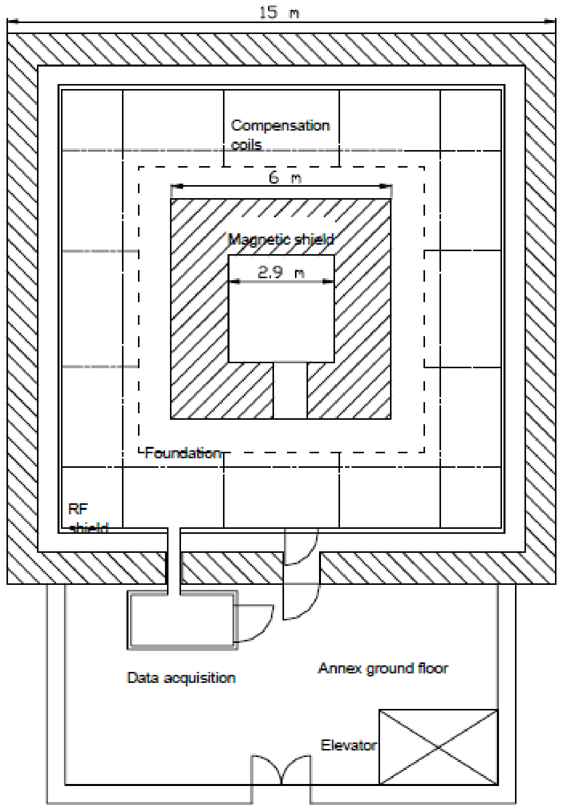
Magnetically-shielded room at PTB, Berlin (Physikalisch Technische Bundesanstalt)

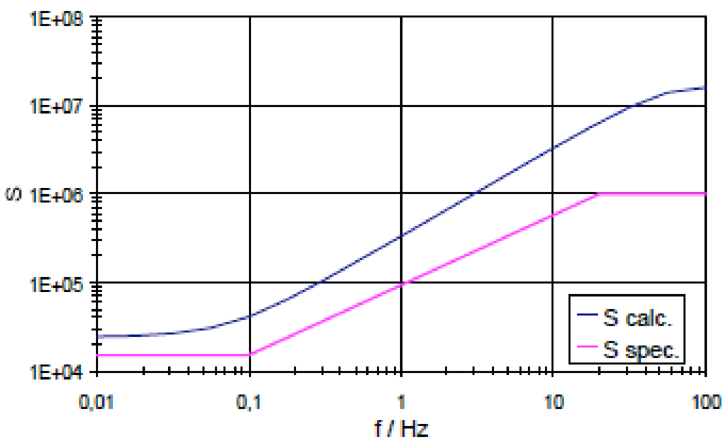
Aim: Achieve noise levels ≈ 1 fT/√Hz in the range 0.001 - 500 Hz.. Ambient noise in the city is ~ nT /√Hz at 1 Hz. A shielding factor S > 10^6 is needed.

7 layers of mumetal, one of Al (10mm, eddy current) + active shielding.

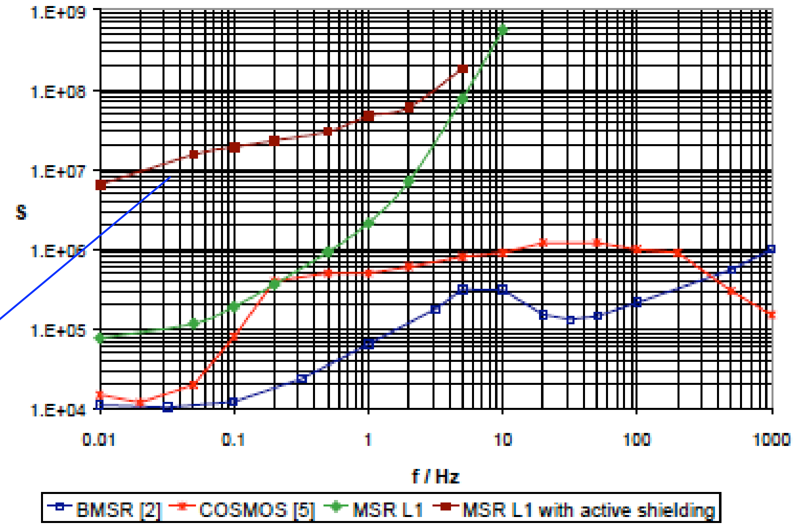


Ambient noise (z-component)





Shielding with passive shields (calculated)

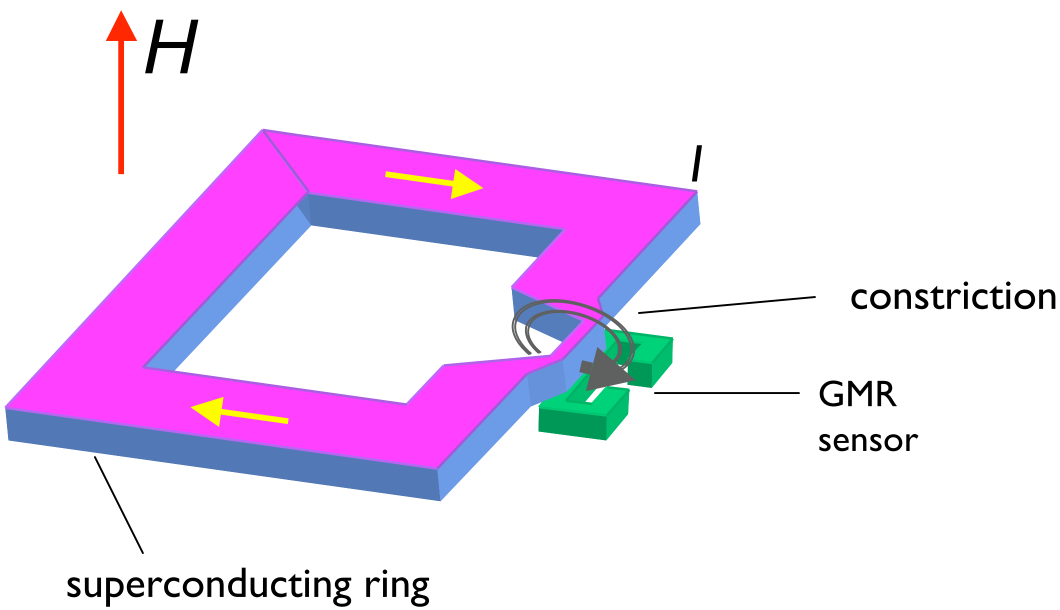


Shielding with active & passive shields (measured)

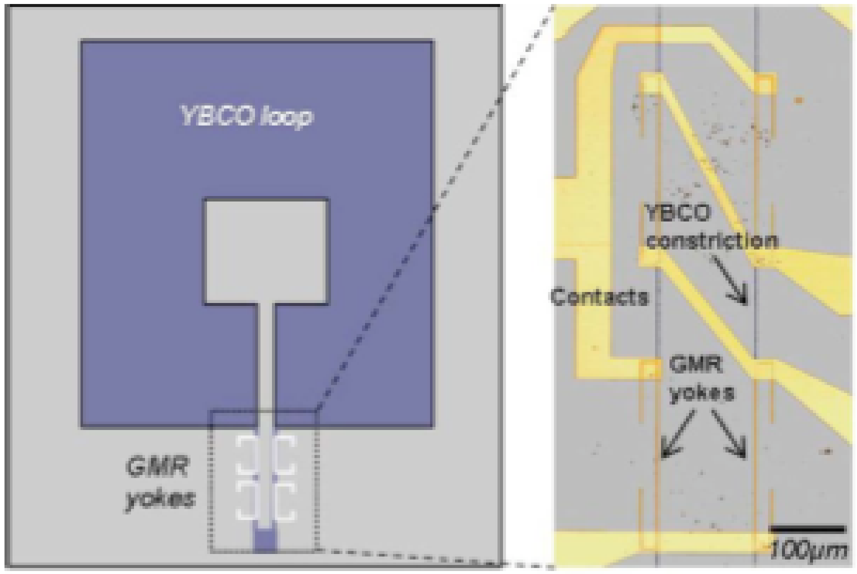
8.3 Mixed Sensor

A hybrid sensor is composed of a superconducting flux to field transformer with a magnetoresistive field sensor.

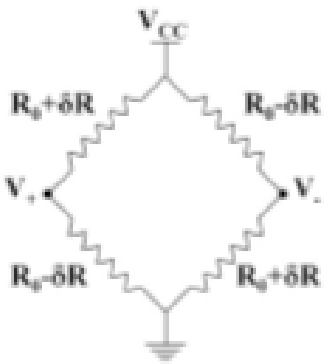
The superconducting loop is made of a low T_c material (Nb) ot a high T_c superconductor $YBa_2Cu_3O_7$ (YBCO). It has a narrow constriction where the circulating current in the loop (the flux threading the loop cannot change, so when the applied field increases, so does the screening current flowing in the loop). The current density is high at the constriction where it creates a stray field that is detected by a GMR sensor



The mixed sensor is simpler than a SQUID A current is induced in the superconducting loop, which is purely passive, in order to exclude flux. Sensitivity approaches the fT level.



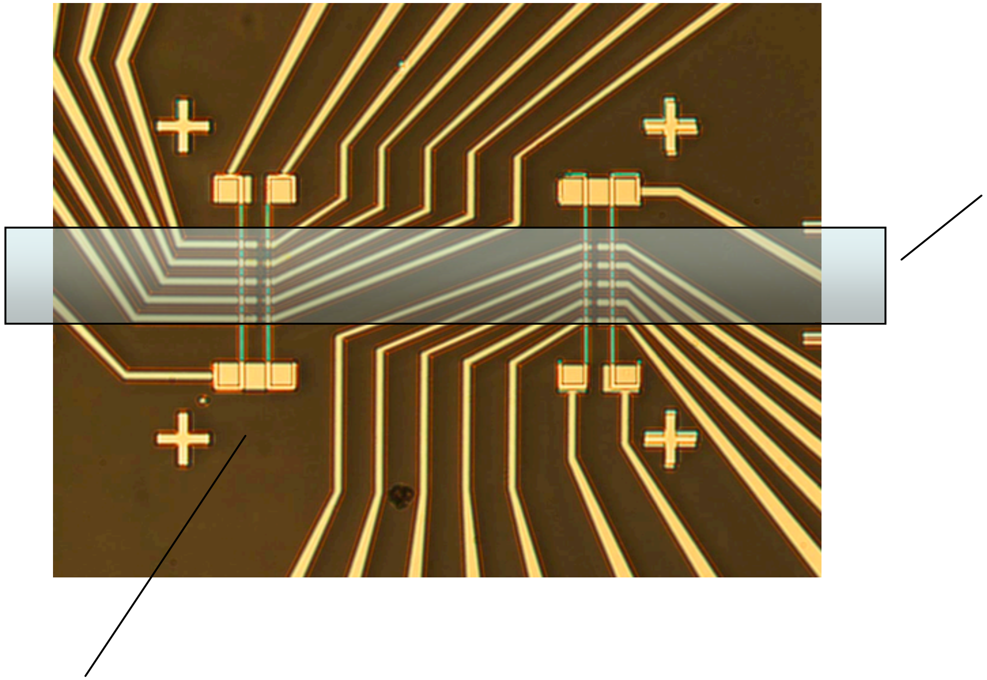
Yoke-type sensors are deposited on the YBCO constriction in a Wheatstone's bridge configuration.

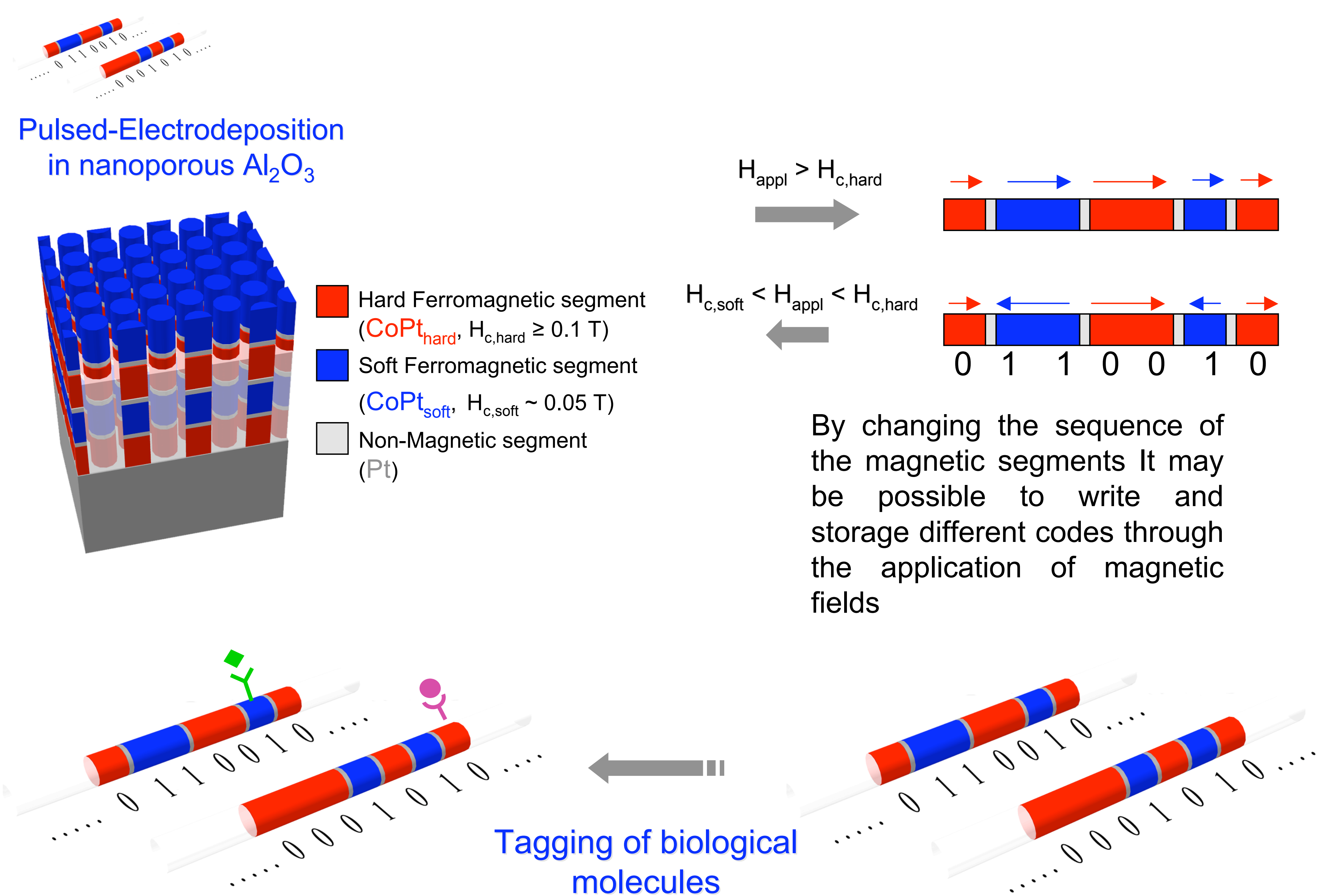


Applications include detection of nmr including NQR of explosives, biomagnetic applications and magnetic imaging.

8.4 Magnetic barcodes

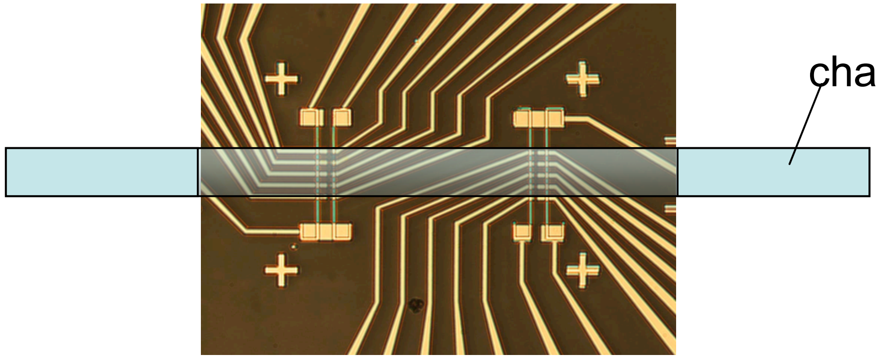
Magnetic labels can be detected in microfluidic channels using GMR of TMR spin-valve sensors.



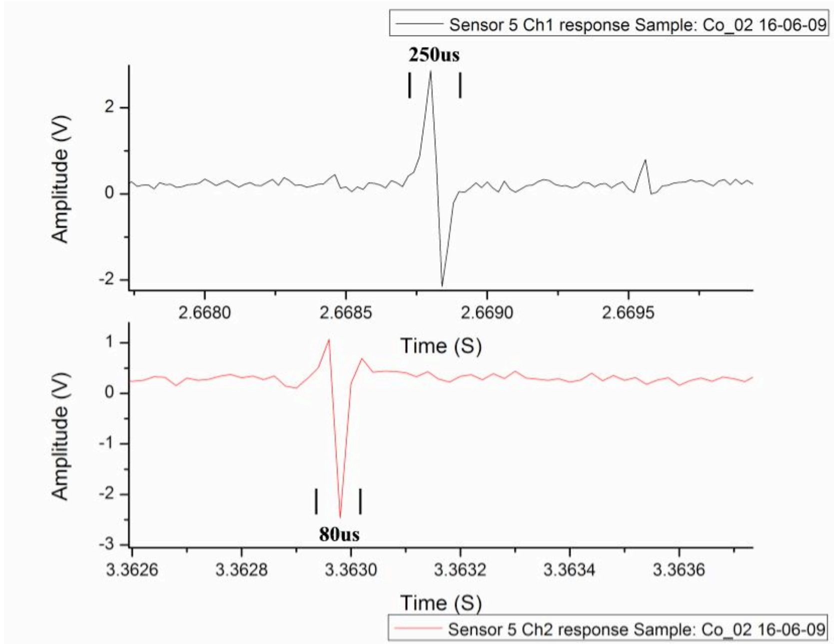


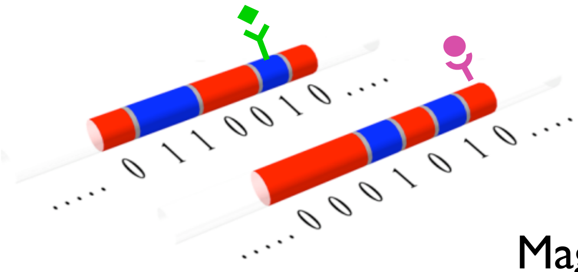
Pulsed-Electrodeposition in nanoporous Al_2O_3
Hard Ferromagnetic segment ($CoPt_{hard}$, $H_{c,hard} \geq 0.1$ T)
Soft Ferromagnetic segment ($CoPt_{soft}$, $H_{c,soft} \sim 0.05$ T)
Non-Magnetic segment (Pt)
$H_{appl} > H_{c,hard}$
$H_{c,soft} < H_{appl} < H_{c,hard}$
0 1 1 0 0 1 0
By changing the sequence of the magnetic segments It may be possible to write and storage different codes through the application of magnetic fields
Tagging of biological molecules

Signals due to *single* nanowire

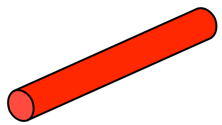


Microfluidic sensor:
Two pairs of yoke-type spin valve sensors for a microfluidic channel





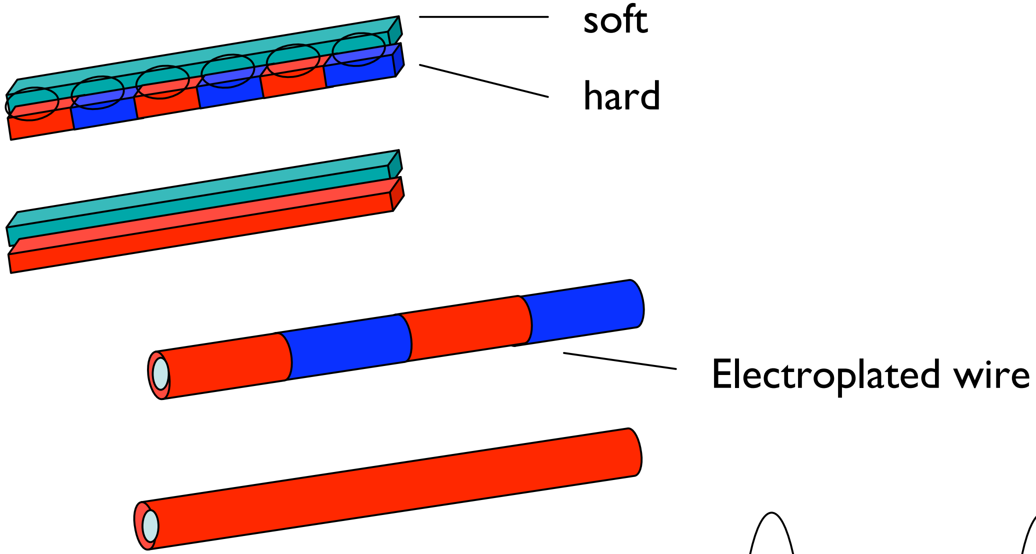
Magnetic barcodes

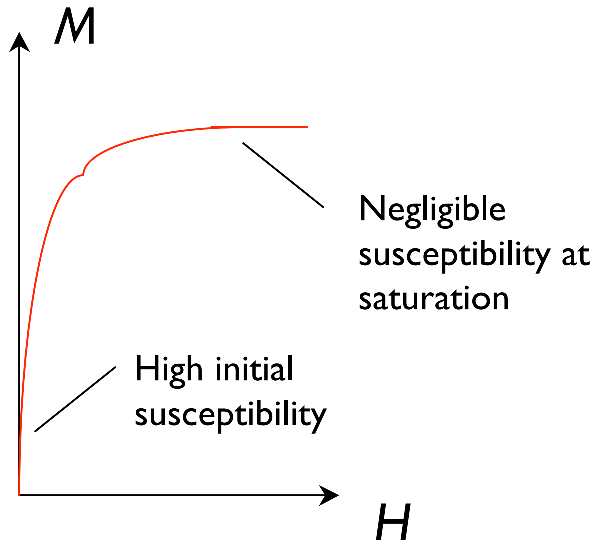


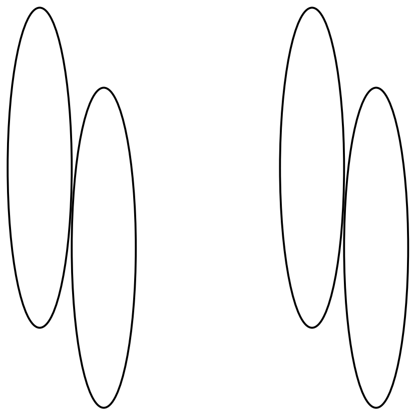
8.5 Security tags.

Merchandise in stores, books in libraries etc. needs to be labelled with deactivateable tags in order to present unauthorized removal.

Bimetallic strip:







Coils at exit, excited at $\approx$ kHz