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Basile Dufay, Sébastien Saez, Christophe Cordier, Christophe Dolabdjian, E.
Hristoforou

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Study of an hybrid magnetometer: YIG



B. Dufay¹, S. Saez¹, C. Cordier¹, C. Dolabdjian¹, E. Hristoforou²

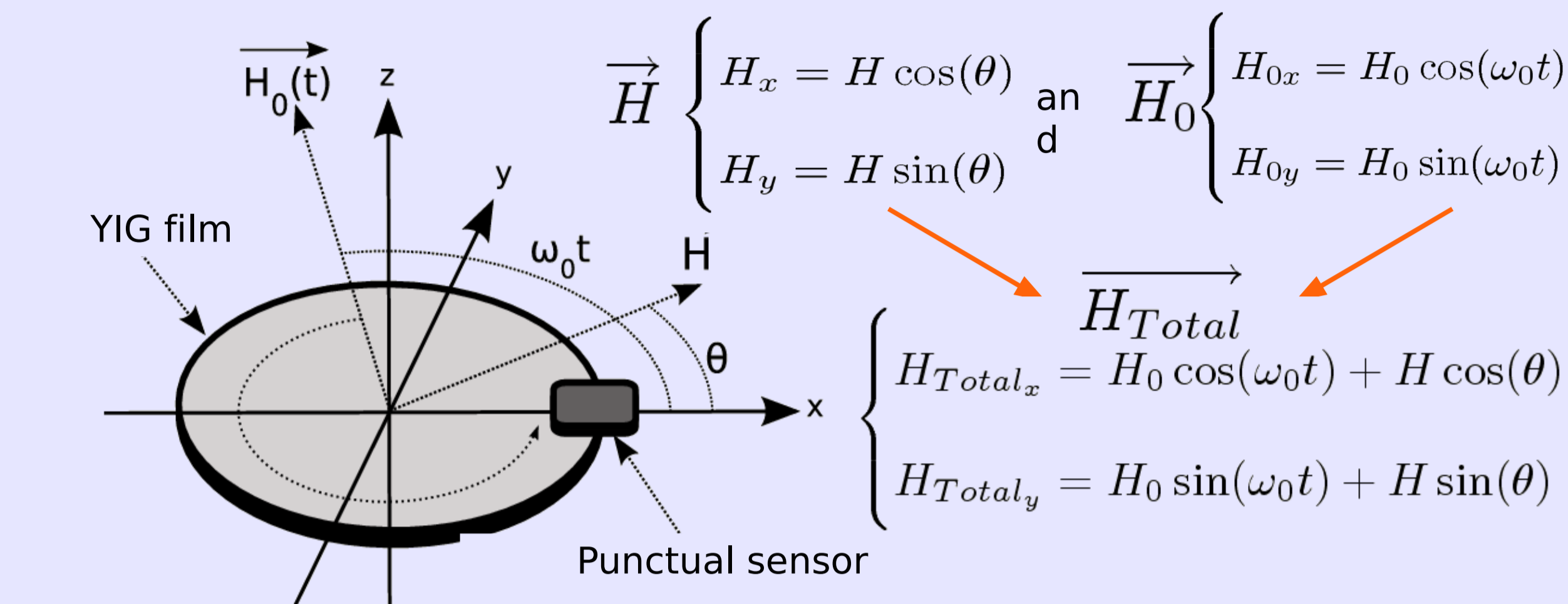
¹GREYC, 6 Bd du Maréchal Juin, 14000 Caen, FRANCE

²Laboratory of physical metallurgy, National Technical University of Athens, Zografou Campus, Athens 15780, GREECE

The work presented here deals with the study of a flux-gate type magnetometer which use a rotating magnetization. This principle allows to sense the different space components of the magnetic field and to reduce the noise due to Barkhausen jumps. The device was set-up at the laboratory of physical metallurgy of the national technological university of Athens.

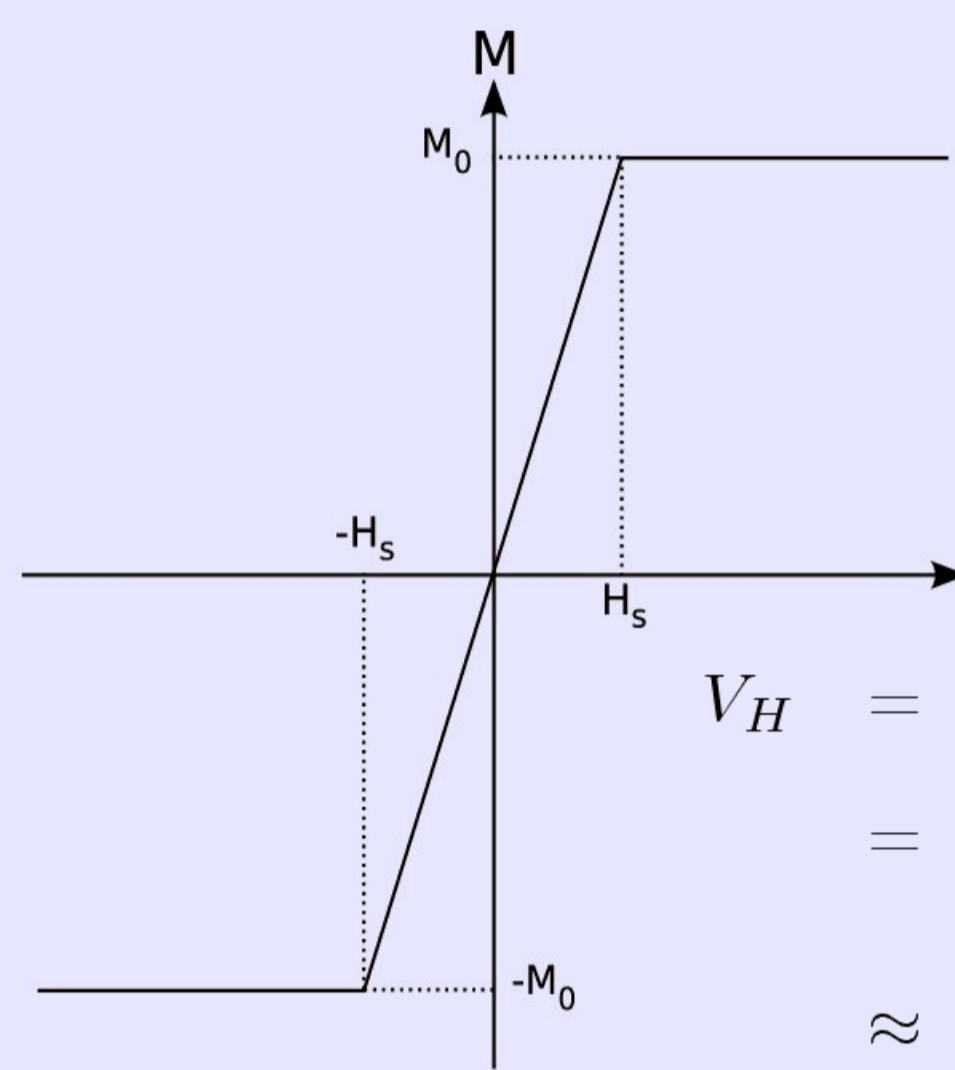
First of all, studying physical properties of the used material allows to deduce his crystalline structure, to evaluate his behavior under a rotating magnetic excitation and to validate the choice of this material. Then, a theoretical approach of the rotating excitation principle allows to understand the interest of this kind of device and to see which elements are changing performances on sensibility or magnetic noise. This theoretical approach finally leads to expose and to analyze the practical realization of using this working principle as developed by the Greek laboratory. It allows to understand encountered difficulties and to evaluate the effect on performances due to compromises needed. Finally, some experimental results are exposed, validating the working principle and leading to think about the possibility of evolution of this device.

Working principle:



If $|\vec{H}_{Total}| \geq |\vec{H}_s|$ the magnetization \vec{M} of the material is saturated so :

$$\begin{aligned} |\vec{M}| &= M_0 \quad \text{and} \\ \arg(\vec{M}) &= \arg(\vec{H}_{Total}) \\ &\approx \omega_0 t - \frac{H}{H_0} \sin(\omega_0 t - \theta) \end{aligned}$$



The punctual sensor sense a signal V_H proportional to M_x :

$$\begin{aligned} V_H &= T_H k M_x \\ &= T_H k M_0 \cos\left(\omega_0 t - \frac{H}{H_0} \sin(\omega_0 t - \theta)\right) \\ &\approx T_H k M_0 \left(\cos(\omega_0 t) + \frac{H}{H_0} (\cos\theta - \cos(2\omega_0 t - \theta))\right) \end{aligned}$$

Demodulation by $\cos(2\omega_0 t)$ and $\sin(2\omega_0 t)$ allows us to deduce both H and θ with a single magnetometer.

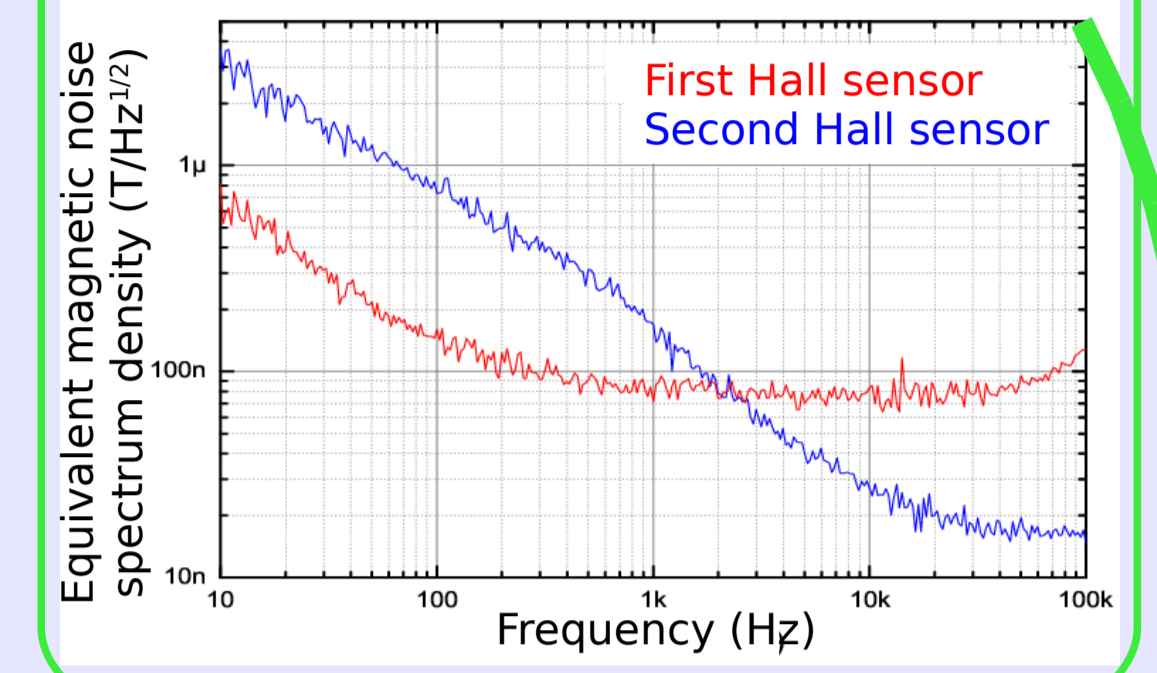
$$\text{SENSITIVITY : } T_r = -\frac{kM_0}{2\mu_0 H_0} T_H = -\frac{kM_0}{2B_0} T_H$$

Noise sources:

Intrinsic magnetic noise [1]

$$\langle H_f^2 \rangle_{\Delta\omega} = \frac{T k_B 10^7}{2\pi V} \frac{\Delta H}{\gamma M^2}$$

Electronic noise dominated by the noise from the punctual sensor



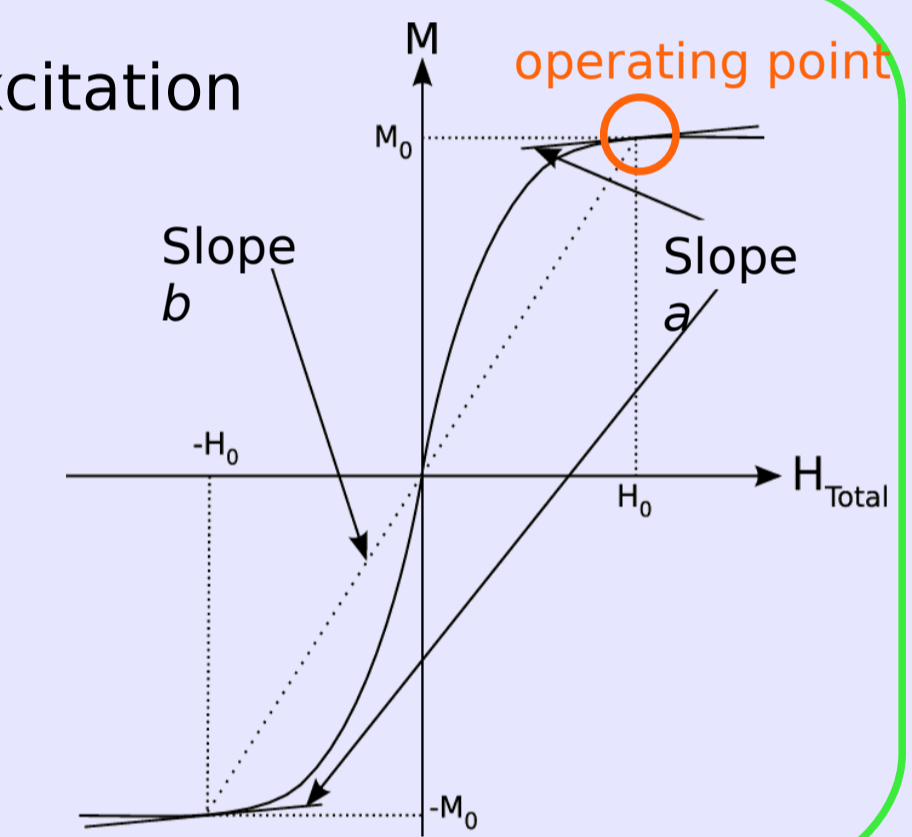
$$V_{Hdem}(t) = \frac{T_H k M_0}{2B_0} B(t) + \frac{T_H k M_0}{2B_0} b_n(t) + \frac{T_H k}{2B_0} B(t) a h_0(t) + e_n(t)$$

Noise from the rotating excitation

M_0 becomes :

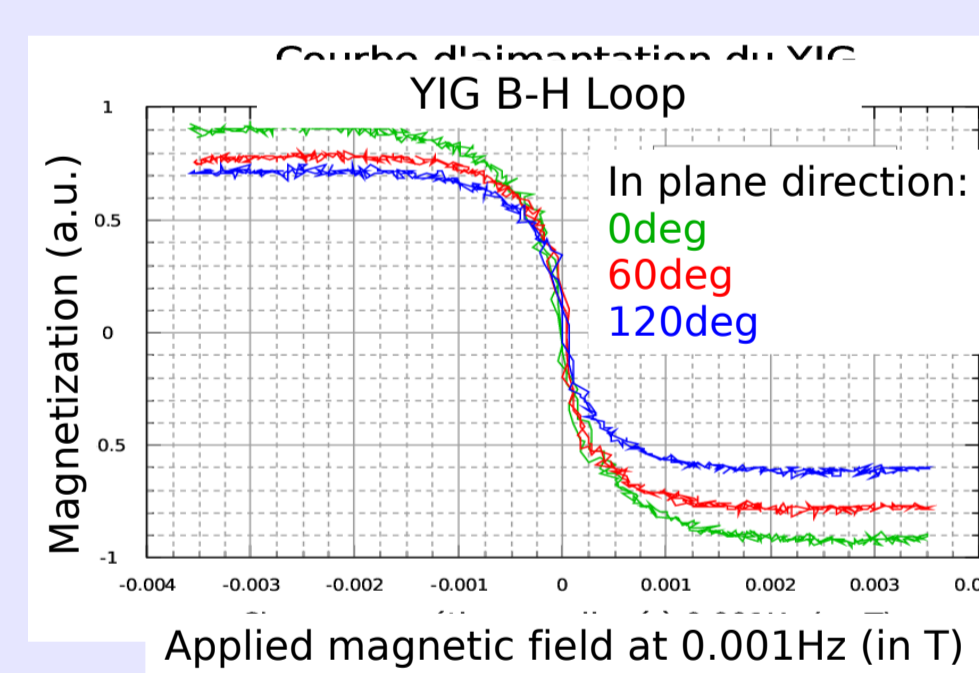
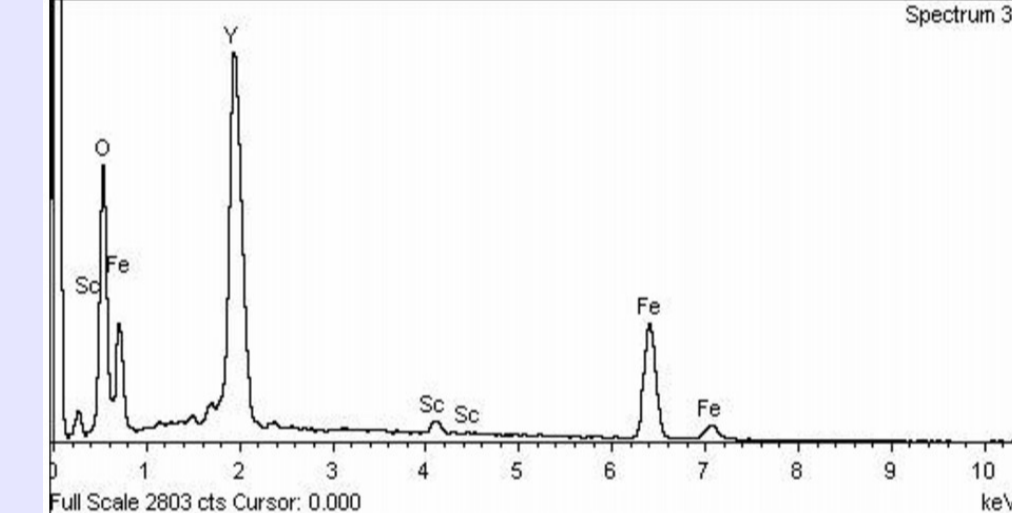
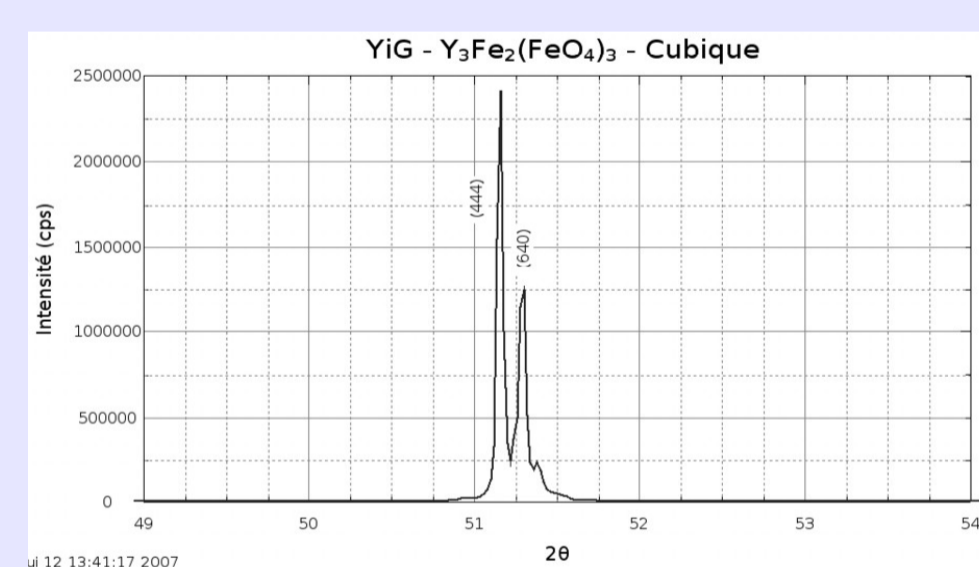
$$M_0 + m_0(t) \approx b H_0 + a h_0(t)$$

$h_0(t)$ is the amplitude noise of \vec{H}_0



Materials:

YIG: SEM, EDS, XRD and B-H Loop measurement.

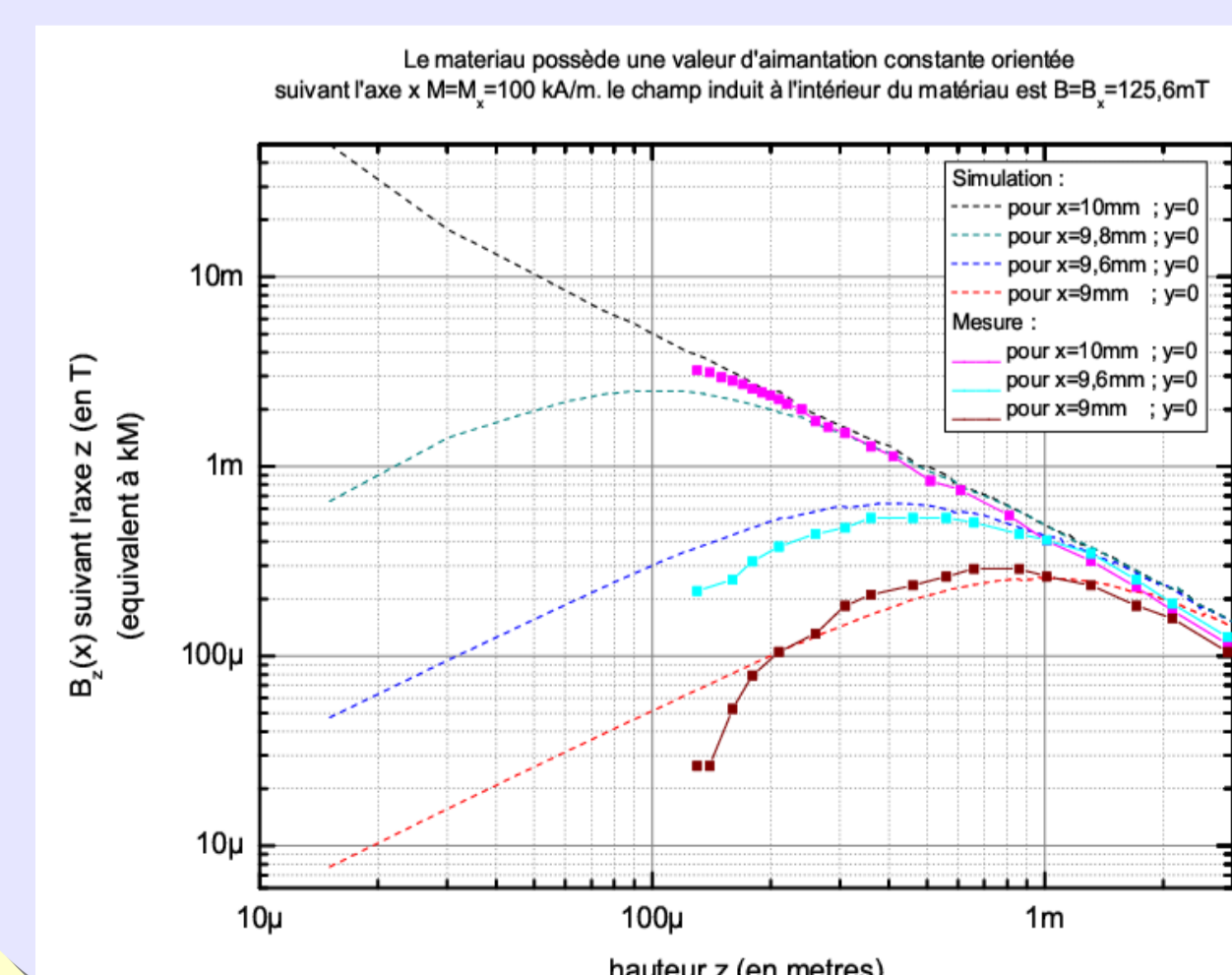


Yttrium Iron Garnet
Single-crystal
YScFeO -> YIG
Solid solution of Sc
Miller level: 640 (in plane) and 444
Strong susceptibility
In-plane anisotropic behavior of the B-H Loop

Implementation:

Punctual magnetometer -> Hall effect sensor, sensing the vertical component of the field induced by the magnetization of the YIG.

k: coupling factor between YIG magnetization M and sensed field.



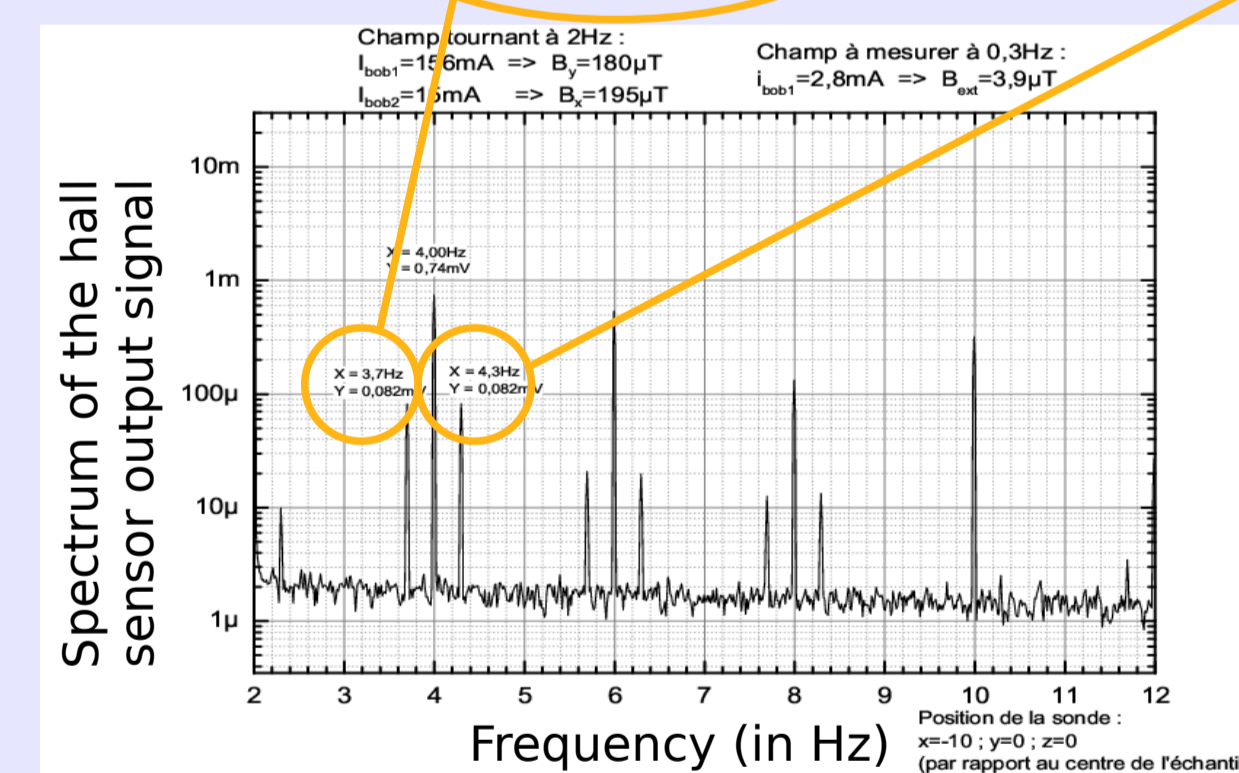
Optimal position of the Hall sensor in order to increase k:
just on the boundary of the YIG disc
as near as possible from the YIG film surface.
increase the space resolution of the sensor in use.

Results:

We apply an external magnetic field: $\vec{H} \begin{cases} H_x = H \cos(\omega t) \\ H_y = 0 \end{cases}$ with $H \ll H_0$

So the sensed output signal becomes:

$$\begin{aligned} V_H &= -T_H k M_0 \frac{H}{2H_0} \cos(\omega t) \cos(2\omega_0 t) \\ &= -T_H k M_0 \frac{H}{4H_0} \cos((2\omega_0 + \omega)t) - T_H k M_0 \frac{H}{4H_0} \cos((2\omega_0 - \omega)t) \end{aligned}$$



The sensitivity T_r could be evaluated from the amplitude of both AM spectral components.

	Excitation field amplitude B_0	kM_0	Sensitivity T_r	Noise power spectrum density in T/\sqrt{Hz}	Example for $f = 10 Hz$
first Hall sensor	Bare Hall sensor		25 V/T	$\frac{8.10^{-6}}{f} + 80.10^{-9}$	$880 nT/\sqrt{Hz}$
	1 mT	850 μT	11 V/T	180.10^{-9}	$180 nT/\sqrt{Hz}$
	180 μT^*	500 μT	35 V/T	at $f_0 \geq 500 Hz$ 60.10^{-9} at $f_0 \geq 500 kHz$	$60 nT/\sqrt{Hz}$
Second Hall sensor used for increasing k	Bare Hall sensor		2 V/T	$\frac{8.10^{-6}}{\sqrt{f}} + 16.10^{-9}$	$2,5 \mu T/\sqrt{Hz}$
	1 mT	2 mT	2 V/T	16.10^{-9}	$16 nT/\sqrt{Hz}$
	180 μT^*	not measured	6 V/T	$5,3.10^{-9}$	$5,3 nT/\sqrt{Hz}$

* Not sufficient in order to saturate the material

Actuals main problems:

- Noise spectrum density is dominated by the hall sensor noise.
- Low values of the coupling factor k .

Possibilities of evolution:

- Increase the coupling factor k : *optimization of the hall sensor position.
- Increase the ration M_0/B_0 : *Changing the form factor of the material
*New soft magnetic material