ESRF	**Experiment title:** *ELLIPTIC PRECESSION PROBED UNDER THE CONDITIONS OF MICROWAVE FREQUENCY DOUBLING*	**Experiment number:** **HE-2854**
Beamline: **ID-12**	**Date of experiment:** from: 29-OCT-2008 to: 04-NOV-2008	**Date of report:** 18-FEB-2009
Shifts: **18**	**Local contact(s):** **A. ROGALEV and F. WILHELM**	*Received at ESRF:*

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1. FREQUENCY DOUBLING IN XDMR

Even though the precession of the magnetization can reasonably be assumed to be circular in perpendicularly magnetized YIG thin films, this does not hold true for in-plane magnetization or for ferrites with a large magnetocrystalline anisotropy. For thin films magnetized tangentially, one usually defines an *ellipticity* factor: $\mathcal{E} = 1 - |m_{min}|^2/|m_{max}|^2$ in which $|m_{min}|$ and $|m_{max}|$ refer to the length of the smallest and largest *transverse* magnetization components. As soon as $\mathcal{E} \neq 0$, the *non-linearity* of the equation of motion implies that there should appear a small *longitudinal* magnetization component $m_z^{(2)} \propto \mathcal{E}$ oscillating and radiating at twice the microwave frequency (2ω). Recall that there is no such *transverse* component $m_t^{(2)}$ oscillating at angular frequency 2ω (nor any even harmonics) as long as the microwave pump field $\mathbf{h_p}$ is *perpendicular* to the bias field ($\mathbf{H_0}$). Our challenge was to check whether there was a detectable XDMR signal associated with the component $m_z^{(2)} \propto \mathcal{E}$ in the case of a YIG thin film rotated at magic angle.

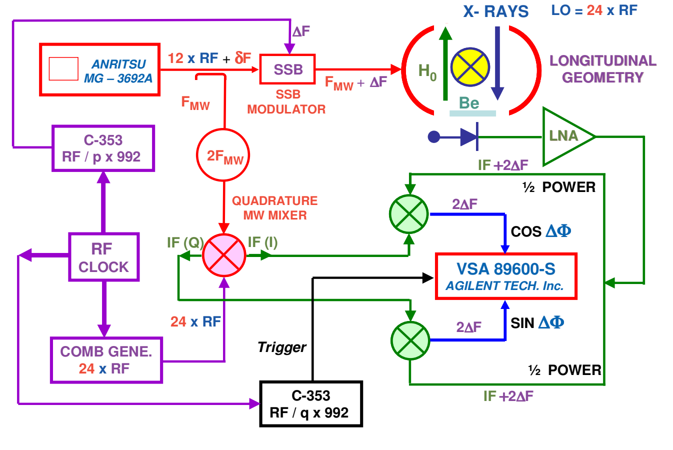


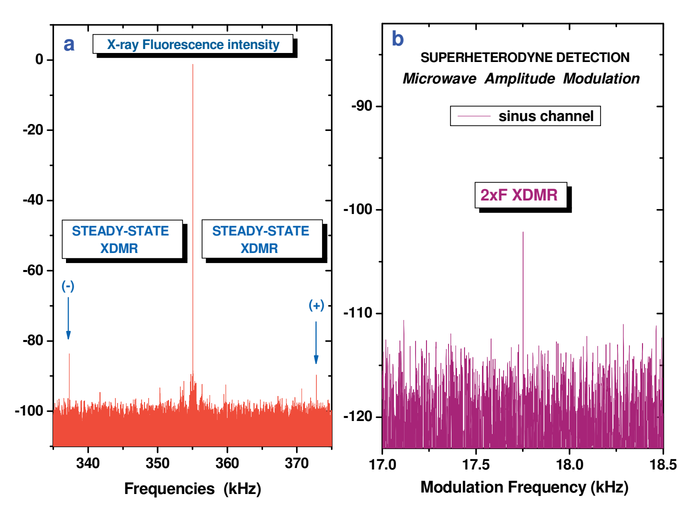
Figure 1: Block diagram of the superheterodyne detection exploiting a Single SideBand (SSB) modulator.

Our strategy was to exploit again the powerful ***heterodyne*** detection technique[1,2] which proved to be successful for probing the transverse component $m_t^{(1)}$ oscillating at the microwave frequency (ω). Here, $m_z^{(2)}$ is expected to be several orders of magnitude smaller than $m_t^{(1)}$. This is where the heavy efforts invested by the ESRF ID12 team in optimizing the performances of a new, fully modular XDMR spectrometer proved to be quite decisive. The block-diagram of the modified superheterodyne detection used for this challenging experiment is shown in Figure 1. The key component is a single sideband (SSB) modulator operated as frequency translator.

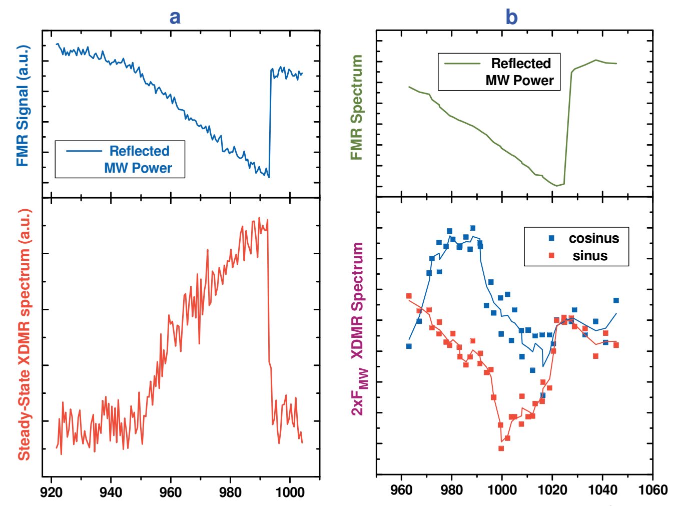
The microwave generator (Anritsu MG 3692A) was tuned to a C-band frequency departing from 12xRF (4.226 GHz) by a small shift δF. Magnetic resonance was pumped in the sample with a microwave field oscillating at frequency: 12xRF+δF+ΔF in which $\Delta F = F_0/p$ is the frequency translation caused by the SSB modulator, F_0 denoting -as usual- the revolution frequency of the electron bunches in the ESRF storage ring. Heterodyne detection of $m_z^{(2)}$ was then envisaged using the 24th harmonics of the RF frequency as a XDMR local oscillator in the microwave X-band: we were thus looking for a *vector* decomposition of the output signal of the photodiode at the intermediate frequency IF+ 2ΔF.

2. RESULTS

The frequency-doubling XDMR experiment was carried out in a now standard longitudinal geometry. The sample was a thin film of YIG/GGG, with the film normal tilted by 54.7° with respect to the bias field $\mathbf{H_0}$. The energy of the circularly polarized X-rays was tuned to the maximum of the Fe K-edge XMCD spectrum.



Figures 2: 2a) Steady-state XDMR signals ∝ $m_z^{(0)}$ measured in the same geometry with an incident microwave power of 1.5W; 2b) Frequency doubling XDMR signal ∝ $m_z^{(2)}$ measured at 2ΔF with an incident microwave power of 2W.



Figures 3: 3a) The steady-state XDMR spectrum ∝ $m_z^{(0)}$ recorded in the field-scan mode exhibits a typical foldover lineshape with *ca.* 30 Oe linewidth. 3b) Vector components recorded in the field-scan mode for the frequency doubling XDMR signal ∝ $m_z^{(2)}$.

As illustrated with the VSA spectrum displayed in Figures 2b, we succeeded in detecting a weak but fully reliable signal ∝ $m_z^{(2)}$ oscillating at twice the incident microwave frequency: its intensity was typically 20 dB below the level of the steady-state XDMR satellites ∝ $m_z^{(0)}$ which were measured under the same conditions in longitudinal geometry. Recall that the frequency-doubling XDMR signal was expected to be very weak in this experimental configuration because there is only a weak (2nd order) contribution[2] of the uniaxial anisotropy to ellipticity $\mathcal{E}$ when the YIG film is rotated at magic angle. This experiment was obviously a critical test of the very high sensitivity achieved with our superheterodyne detection.

We have reproduced in Figures 3 the XDMR spectra recorded in the field-scan mode for the steady-state signal ∝ $m_z^{(0)}$ (Fig. 3a), and for the two frequency-doubling vector components ∝ $m_z^{(2)}$ (Fig. 3b). Whereas the the phase invariant steady-state XDMR spectrum exhibits a typical foldover lineshape[2], it seems that the two vector components ∝ $m_z^{(2)}$ would be much less sensitive to the foldover effect. Further work is in progress in order to explain this hardly predictable result.

Anyhow, this report clearly confirms that frequency-doubling XDMR at the Fe K-edge can perfectly be used to probe the ellipticity of the precession of *orbital* magnetization components.

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