

## Abstract

The current design, and material implementation of the magnetic field sensing in the LTP is based on a set of 4 high-precision 3-axis fluxgate magnetometers. In order to avoid magnetic disturbances on the TMs, originated by the sensors themselves, these are placed somewhat far from the TMs, which results in partial losses field information. We are currently investigating alternative magnetic sensing techniques, based on AMR devices (magneto-resistors). These are much smaller in size than fluxgates, therefore a more numerous array can be thought of for flight. In addition, there is a chance that they may be attached closer to the TM, thereby enhancing magnetic field sensing spacial resolution. Several issues need to be addressed, such as real sensitivity (including electronics noise) and set/reset trigger procedures. By other hand a brief overview about the stability of the magnetic fields and gradients generated by the coil will be given. This poster will show the latest results of our research.

## Introduction

### Magnetic Field Measurements

The magnetometers used in LISA *Pathfinder* are fluxgate type. One of its principal characteristics is the low noise obtained in the bandwidth between 1mHz and 30mHz, however this sensor is bulky and it has some disadvantages:

- Sensor head is large, hence has limited space resolution.
- They need to be placed far from the TMs due to the quantity of permalloy (nickel-iron) contained in the fluxgate's core
- High cost

We have done some preliminary research to assess the performance of AMR sensors in both the LTP and LISA frequency bands.



FIGURE 1: Fluxgate and AMR sensors.

### Magnetic Fields and Gradients Generation

Stability of the magnetic field and gradients created by the coil must comply with requirements depending of the TM distance. To measure the stability of the created magnetic field, is equivalent to measuring the stability of driving current, hence these requirements are equivalent to a current fluctuation in the current source.

## Front-End Electronics

The Analog signal conditioning circuit is shown in the next figure:

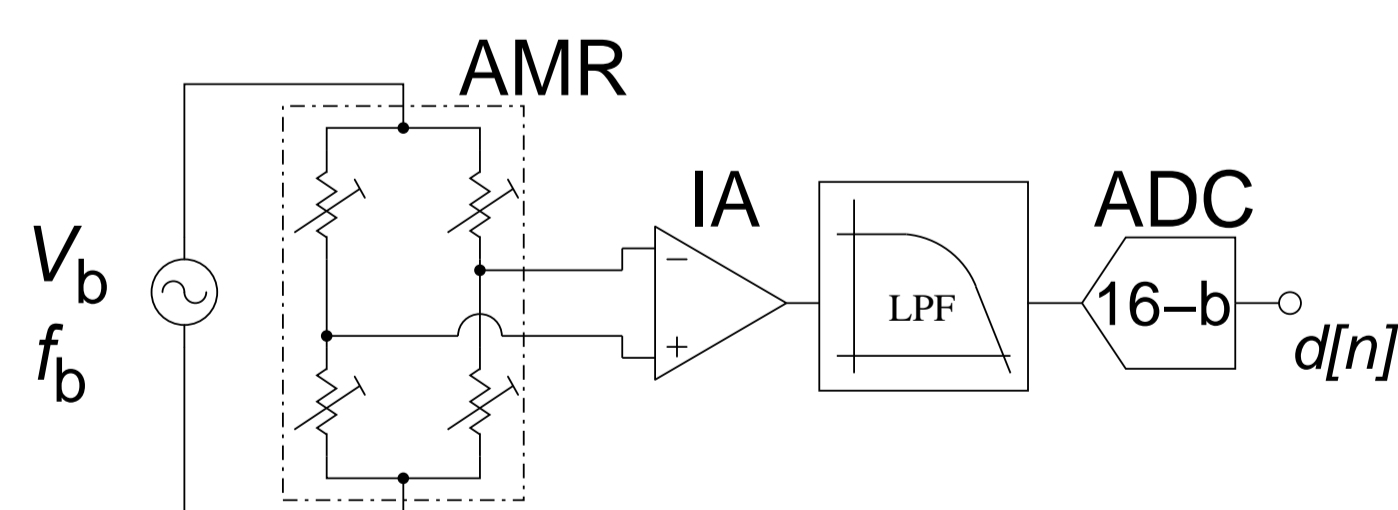


FIGURE 2: Block diagram of the analog acquisition.

The characteristics of the AMR resistance can be modeled as:

$$R(H_y) = R_0 + \Delta R \frac{H_y}{H_0} \sqrt{1 - \left(\frac{H_y}{H_0}\right)^2} \quad (1)$$

and the output voltage of a Wheatstone bridge with four sensor can be described by:

$$V_o = V_B \frac{\Delta R}{R_0} \frac{H_y}{H_0} \sqrt{1 - \left(\frac{H_y}{H_0}\right)^2} \quad (2)$$

Therefore the sensitivity ( $dV_o/(dH_y V_B)$ ) of the entire bridge is  $S_o = \frac{\Delta R}{R_0} \frac{1}{H_0}$  and it has a value around of 16 mV/Gauss in the temperature range of -25 to 100 °C.

The Wheatstone bridge is powered with an ac square signal. This switching helps to reduce the noise by modulating the low frequency signals of interest to a higher band, where the noise is lower.

The gain of the IA has been set to 200, therefore the sensitivity is :

$$S_{IA} = S_b \cdot G_{IA} = 3.2 \text{ V/Gauss} = 32 \text{ mV}/\mu\text{T} \quad (3)$$

The digital processing consists, basically, on a decimator and a subsequent difference averaging that results in a digital demodulation.

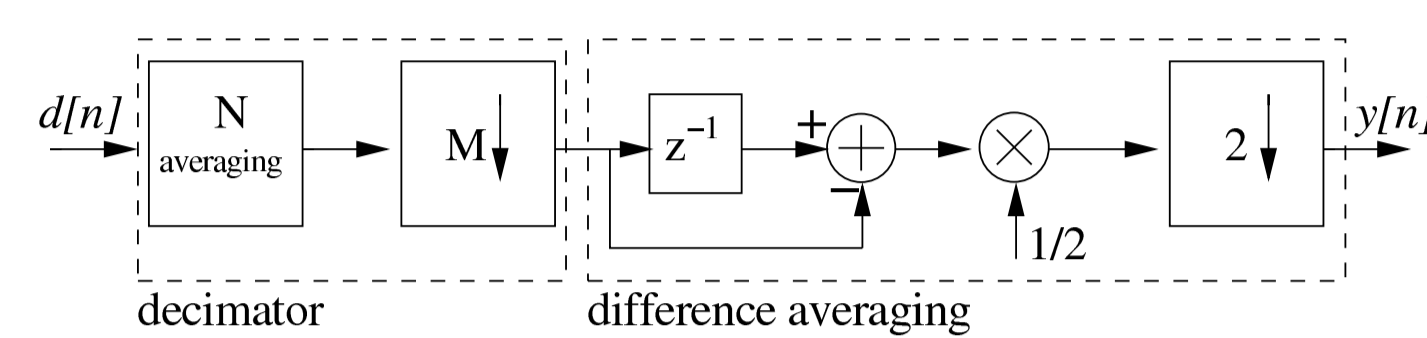


FIGURE 3: Digital processing measurement chain.

## Noise density in the AMR Sensor

The total noise of the measurement chain in terms of magnetic field spectral density can be expressed as:

$$S_H^{1/2}(H, \omega) = [S_{H,b}(H, \omega) + S_{H,IA}(H, \omega) + S_{H,ADC}(H, \omega)]^{1/2} \quad (4)$$

where:

- $S_{H,b}(H, \omega)$  : Bridge noise density
- $S_{H,IA}(H, \omega)$  : Instrumentation amplifier noise density
- $S_{H,ADC}(H, \omega)$  : Analog to digital converter noise density

Fluxgate and AMR Magnetic field noise show similar behavior at interested frequency for LISA (0.1 mHz). Between 1mHz to 30 mHz both are below the requirements LTP.

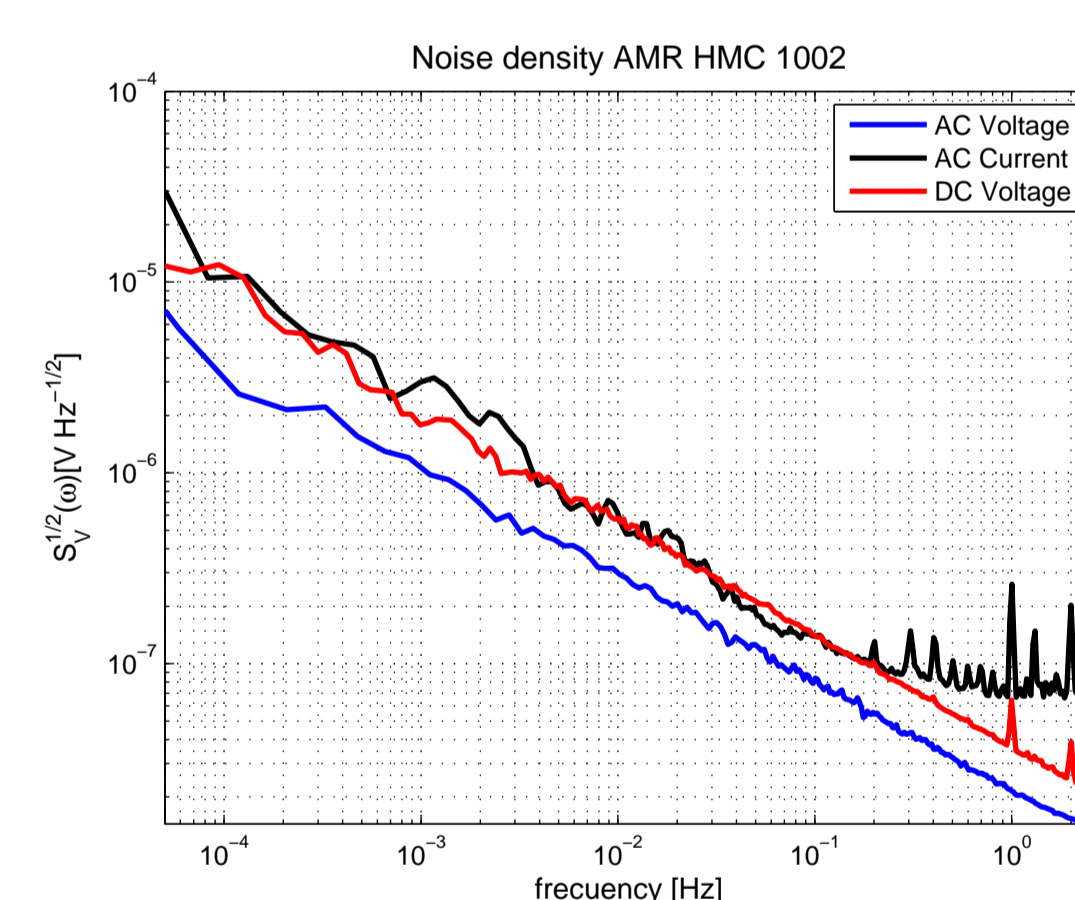
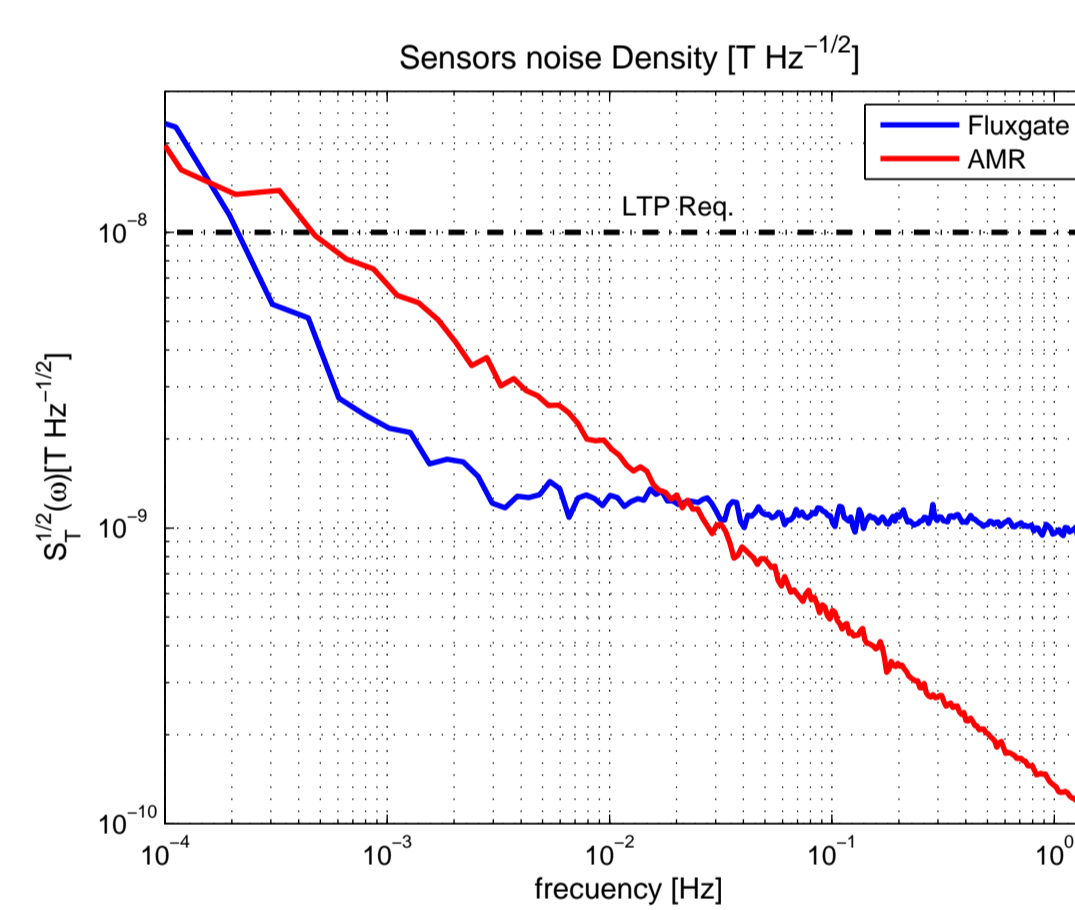


FIGURE 4: Voltage Noise density of the AMR with different Wheatstone Bridge excitation method .

## Magnetic characterization of the AMR

AMR sensor is made of a nickel-iron thin film deposited on a silicon wafer and is patterned as a resistive strip. These materials can show ferromagnetic behaviors (except Silicon that shows diamagnetism) and could be potentially dangerous if they are to be attached near the test mass. Moreover the AMR film properties are well behaved only when the film's magnetic domains are aligned in the same direction (Material saturated).

Most low field magnetic sensors will be affected by a large magnetic disturbing field ( $> 3$  Gauss) that may lead to output signal degradation. This disturbing field actually breaks down the magnetization alignment in the Permalloy film. In order to reduce this effect, a large current Set/Reset pulse of  $2 \mu\text{s}$  can be applied to eliminate the effect of past magnetic history. The state of these magnetic domains can retain for years as long as there is no magnetic disturbing field present ( $\approx 6 \cdot H_{\text{Earth}}$ ).

Due to the strong magnetic requirement in the mission, the magnetic moment of the AMR HMC1001 was measured in a SQUID. We are interested in the saturation magnetic moment because it will be the operation normal state of the AMR.

The measured hysteresis curve shows a saturation magnetic moment of  $m_{\text{sat}} \approx 0.44 \mu\text{Am}^2$ , more than an order of magnitude below the remanent magnetic moment of the NTC ( $m_r \approx 26 \mu\text{Am}^2$ ) placed in the electrode housing in LPF and at a distance of  $\approx 13$  mm of the TM!!.

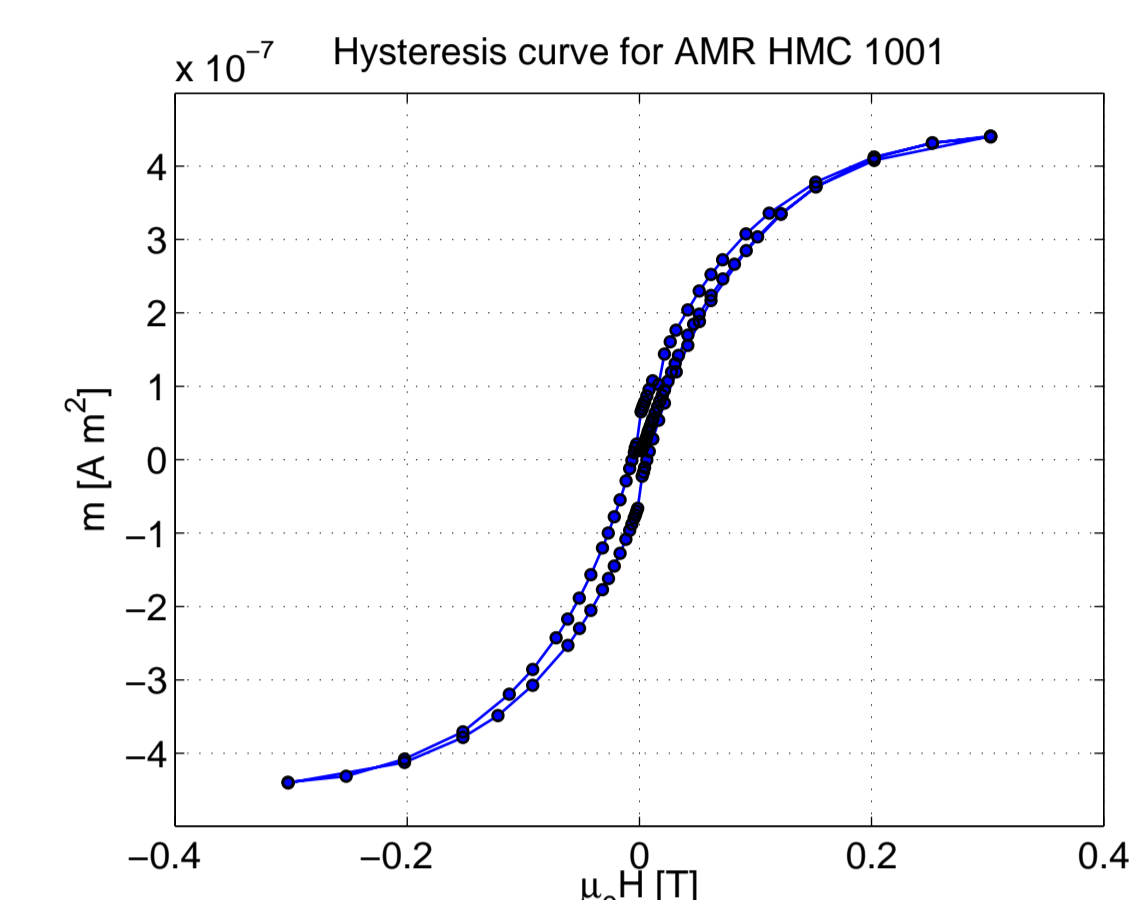


FIGURE 5: Hysteresis curve at 300 K for the AMR HMC1001 .

Magnitude	dc Req.
$B_z$	$10 \mu\text{T}$
$\partial B_z / \partial x$	$5 \mu\text{T/m}$

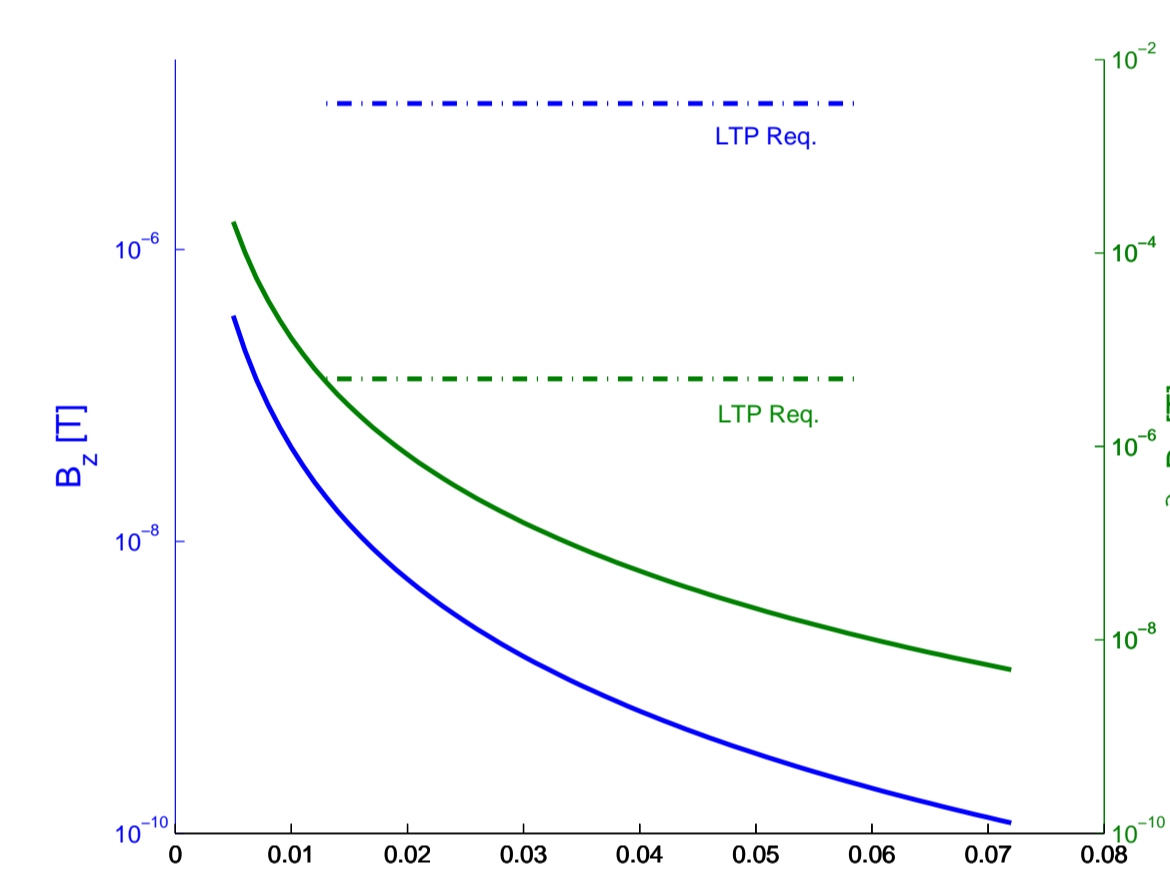


FIGURE 6: Magnetic field (blue) and magnetic field gradient (green) created by a AMR.

## Controlled magnetic excitations: Coil current stability

Different current sources typologies have been tested at LISA Bandwidth, obtaining the best result with the *floating load current source*, although the *differential current source* typology could be a good option, within the requirements too.

Typology	1 mHz			0.1 mHz		
	$S_I^{1/2}$	$S_B^{1/2} (*)$	$S_{\partial B / \partial x}^{1/2} (*)$	$S_I^{1/2}$	$S_B^{1/2} (*)$	$S_{\partial B / \partial x}^{1/2} (*)$
	$\frac{\text{nA}}{\sqrt{\text{Hz}}}$	$\frac{\text{pT}}{\sqrt{\text{Hz}}}$	$\frac{\text{nT}}{\text{m}\sqrt{\text{Hz}}}$	$\frac{\text{nA}}{\sqrt{\text{Hz}}}$	$\frac{\text{pT}}{\sqrt{\text{Hz}}}$	$\frac{\text{nT}}{\text{m}\sqrt{\text{Hz}}}$
Floating load	6	26.8	0.65	34	152	3.71
Differential	17	76	1.86	80	357.8	8.74
Holland	50	223.6	5.46	210	939.2	22.94

(\*) To estimate  $S_B^{1/2}$  and  $S_{\partial B / \partial x}^{1/2}$  have been taken in account a coil's meas radius of 56.5 mm and a distance TM center-Coil center of 85.5 mm (Actual LTP configuration)

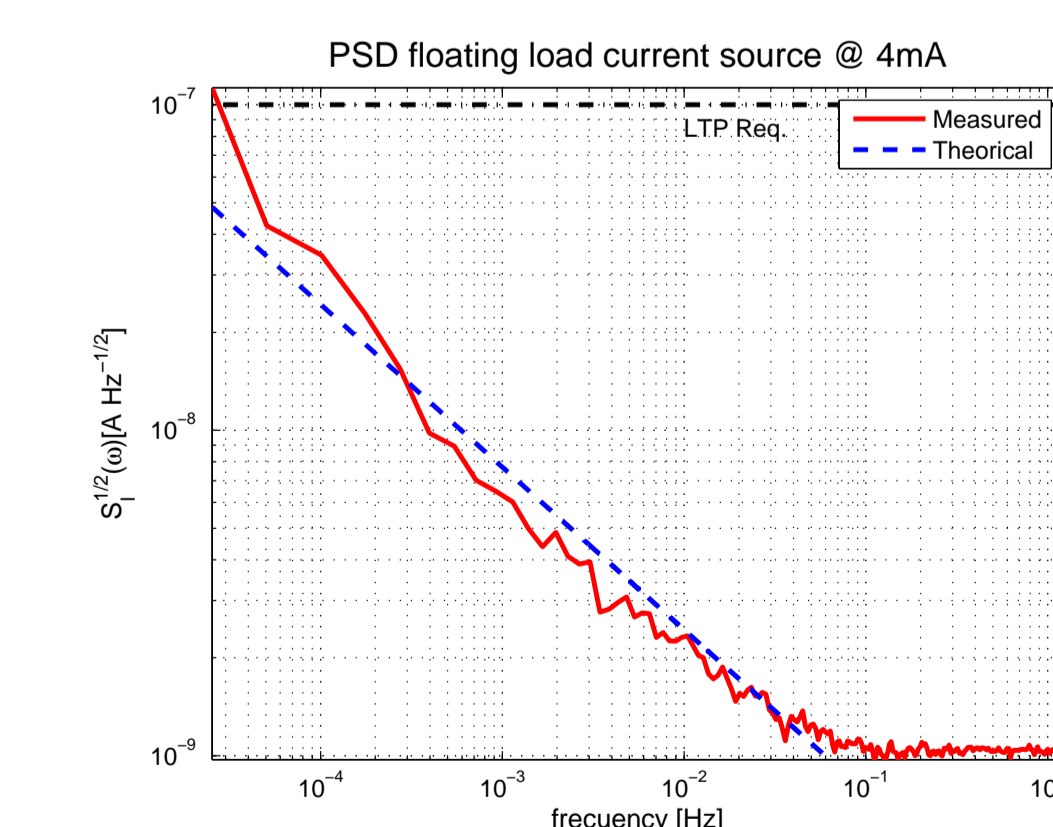


FIGURE 7: Current noise density of the *Floating load* current pump.

## Conclusions

- AMR sensors are smaller and lower power consumption than fluxgate.
- AMR within the LTP magnetic noise requirements.
- Possibility to be placed nearer to TM (low magnetization).